Sustaining Coral Reef Fisheries of Puerto Rico

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Report of Technical Workshops #1 and #2
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Fisheries Technical Workshop #1 and #2
"Length-Based Stock Assessment of Puerto Rico Reef Fishes & Computer-based Tools Laboratory"

Conveners: Drs. Jerry Ault and Steve Smith, Mr Nathan Vaughan, and Ms Natalia Zurcher, University of Miami's Rosenstiel School of Marine and Atmospheric Science.

Local Host: Dr. Craig Lilyestrom, Puerto Rico Dept. of Natural and Environmental Resources

Locations: May 8-9, 2013. San Juan, Puerto Rico. DNER Library 4th Floor
September 4- 6, 2013. Joyuda, Puerto Rico. DNER Fisheries Research Laboratory

Workshop Goals.- The goals of this 3-day technical workshops will be to (1) present research results on the development and application of length-based approaches to sustainability analysis of Puerto Rico reef fishes, and (2) to conduct hands-on training in the use of computer tools for length-based stock assessment and for management forecasting. On workshop Day 1, research results will be presented on data assimilation, analysis, and modeling aspects of length-based assessments of Puerto Rico reef fishes. On workshop Day 2, a laboratory will be conducted for training in the use of the MAST computer tool for carrying out length-based assessments. On workshop Day 3, participants will build up the results they found on day 2 by brainstorming management actions which could be implemented given the assessment results. They will then run simulations to investigate the potential outcomes of their management ideas using the MAST platform.

Target Audience.- This workshop is intended for reef fisheries scientists and managers from government and academia, as well as representatives from the commercial and recreational fishing communities and non-governmental organizations in Puerto Rico. This workshop will accommodate participants based in the Mayaguez regions.

Background.- The coral reef fisheries of the Puerto Rico reef ecosystem support multimillion-dollar fishing and tourism industries. The sustainability of these fisheries is a key conservation concern given their economic and ecological importance, the significant dependence of subsistence and artisanal fishers on reef fisheries for their livelihoods, and the considerable and growing threats to coral reef habitats (i.e. coral bleaching and disease, pollution and climate change). Sustainability refers to the ability of an exploited stock to produce goods and services, including yields at suitable levels in the short term, while maintaining sufficient stock reproductive capacity to continue providing these goods and services into the indefinite future. The data- and model-limited situations confronting most coral reef fisheries, including those of Puerto Rico, have hampered application of modern stock assessment techniques that meet the legal mandate of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). We have developed a class of length-based methods for stock assessment of data-limited fisheries (Ault et al. 2008). These approaches have relatively simple data requirements, provide a community-level perspective on exploitation effects, and also enable evaluation of stock-specific sustainability that conforms to the legal requirements of the MSFCMA.

TABLE OF CONTENTS

OVERVIEW

The sustainability of coral reef fisheries of the Puerto Rico reef ecosystem is a critical ecological and economic concern as it is, inhabited by hundreds of reef fishes and macroinvertebrates, and supports multimillion-dollar fishing and tourism industries. Towards this end and with assistance from DNER personnel, length composition data were obtained from long-term fishery-dependent and fishery-independent sampling programs with focus on the two principal fishery-dependent sampling programs, the Trip Interview Program (TIP) that samples commercial catches and the Marine Recreational Fisheries Statistical Survey (MRFSS) that samples recreational catches. Unique capacity has been built within the Ault lab at the University of Miami to utilize these data sources for rigorous stock assessment when they were traditionally considered insufficient. To support this work both fundamental advances in development of analytical models for length based mortality assessment and the construction of a computational platform for fishery simulation (MAST) has been achieved. The results of this latest assessment continue to support the conclusion that the majority of species in the Puerto Rican fishery are significantly over exploited. There is evidence that organic transition is occurring within the commercial fishery to reduce effort and increase minimum capture size as seen in the TIP data. However management action is still required as a budding recreational fishery possesses the potential for rapid expansion which would negate and possibly reverse the positive trends being seen from the changing commercial fishery. Particular concern should be given to the parrotfish complex which display extreme overexploitation and the grouper complex which while virtually absent still make intermittent appearance in the catch data suggesting that their populations may have already undergone collapse.

INTRODUCTION

The coral reef fisheries of the Puerto Rico reef ecosystem, inhabited by hundreds of reef fishes and macroinvertebrates, supports multimillion-dollar fishing and tourism industries (**Fig. 1**). The sustainability of multispecies coral reef fisheries in Puerto Rico is a key conservation concern given their economic and ecological importance, the significant dependence of subsistence and artisanal fishers on reef fisheries for their livelihoods, and the considerable and growing threats to coral reef habitats (i.e. coral bleaching and disease, pollution and climate change).

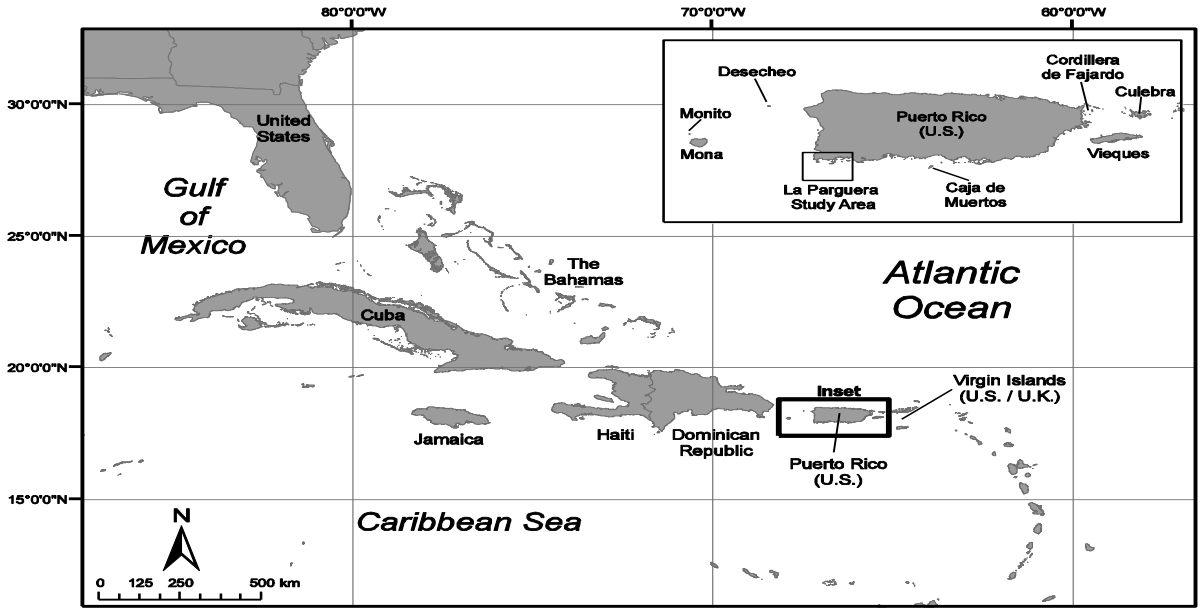


Figure 1.- Map of the northern Caribbean Sea, with inset showing the island archipelago of Puerto Rico and the La Parguera region.

Sustainability refers to the ability of an exploited stock to produce goods and services, including yields at suitable levels in the short term, while maintaining sufficient stock reproductive capacity to continue providing these goods and services into the indefinite future. The data- and model-limited situations confronting most coral reef fisheries, including those of Puerto Rico, have hampered application of modern stock assessment techniques that meet the legal mandate of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). The objective of this research is to develop a quantitative toolbox of data assimilation and length-based fishery assessment methods to compute reference points for the multispecies coral reef fisheries that will facilitate the conservation efforts of state and federal managers and increase regional capacity to build sustainable reef fisheries in Puerto Rico. Our proposed approach is novel in that it has relatively simple data requirements and provides a community-level perspective on exploitation effects, yet also enables evaluation of stock-specific sustainability that conforms to the legal requirements of the MSFCMA. The long-term conservation outcome is to achieve sustainable levels of fishing for exploited groupers, snappers, and parrotfishes in Puerto Rico through development of new framework of

assimilation and modeling methods and by working closely with regional managers and scientists to implement the framework.

Major Threats and Opportunities

Intensive exploitation and overfishing are perhaps the major threats to this ecosystem. Overfishing has been identified as one of the top three global threats by the NOAA Coral Reef Conservation Program. Substantial reductions in commercial reef fish catches in Puerto Rico over the past several decades have been observed, resulting in harvest moratoria on several species (for example Nassau grouper and goliath grouper). At risk are the economic well-being of coastal human communities as well as the ecological resilience and sustainability of the coral reef ecosystem. Reef fisheries in Puerto Rico target important guilds of fish species including top predators (e.g., groupers and snappers) and herbivores (e.g., parrotfishes). Overfishing not only threatens the long-term viability of individual species, but also impacts the overall health of the coral reef ecosystem. For example, depletion of top predators can disrupt the ecosystem food web, and depletion of herbivores can give a competitive advantage to algae over coral for available substrate, in turn leading to loss of coral cover and general degradation of coral reefs. The end result of these impacts may be a general decline in the productive capacity of the coral reef ecosystem to produce fishery yields and an increased vulnerability to climate change.

Insufficient and poor quality data, and lack of an appropriate modeling framework have prevented sophisticated evaluations of the sustainability of reef fisheries. Generally lacking are the data needed to conduct modern stock assessments, including demographic rates and historical time-series of age-size structured catches by species, and the associated fishing effort by gear and sector. While the quality and scope of reef fishery catch-effort data have generally improved in Puerto Rico over the past two decades for the commercial fleet, comparable data from the recreational fleet are not available prior to 2000. There is an obvious lack of a quantitative framework to assess the sustainability of reef fishes in Puerto Rico and to guide management decision-making.

An opportunity to overcome these data and model limitations has recently been provided by Ault et al. (2008), who developed a new quantitative system of length-based empirical estimation and numerical model analyses to evaluate exploitation status via resource reference points (or sustainability benchmarks) for coral reef fishes of the snapper-grouper complex in Puerto Rico. Of the 25 reef fish species assessed, 16 were overfished according to federal benchmarks for sustainability, six were fished sustainably, and three could not be reliably determined due to insufficient data. These findings indicate that a majority of snapper-grouper species in Puerto Rico are currently fished at unsustainable levels.

Over the past decade, requirements for fishery assessment and management in the USA have moved towards a more precautionary approach that strives to 'prevent overfishing while achieving, on a continuing basis, the optimal yield from each fishery for the United States fishing industry' (MSFCMA [Magnuson-Stevens Fishery Conservation and Management Act]. Under this legal framework, determination of the sustainability of a fishery must also consider relevant socioeconomic and ecological factors, particularly whether fishing could deleteriously

impact the reproductive capacity of the resource. This new process involves regulation of fishing mortality rate, over which management has some direct control, and how it should change depending upon stock reproductive potential and associated fishery yields. The data limited situations confronting coral reef fisheries in Puerto Rico have hampered application of modern stock assessment techniques that meet the legal mandate of the MSFCMA.

The use of length composition data and associated models to assess Caribbean reef fisheries is relatively novel, and the analysis of Ault et al. (2008) represented a first attempt to apply these assessment methods across the exploited reef fish community in Puerto Rico. There are some advantages to this length-based assessment method for estimating total mortality because it has relatively simple data requirements and has been shown to have relatively robust properties for assessing exploitation impacts on coral reef fishes. Unique owing to its zero-bias properties at equilibrium, the method is also relatively insensitive to trends in recruitment and exhibits desirable properties for detecting statistical differences between sustainable and non-sustainable rates (Ehrhardt and Ault 1992; Ault et al. 2005). It also enables evaluation of stock-specific sustainability that conforms to the legal requirements of the MSFCMA.

1.0 DATA SOURCES AND PROCESSING

Length composition data were obtained from long-term fishery-dependent and fishery-independent sampling programs with the assistance of DNER personnel (**Table 1.1**). Initial analyses focused on the two principal fishery-dependent sampling programs, the Trip Interview Program (TIP) that samples commercial catches and the Marine Recreational Fisheries Statistical Survey (MRFSS) that samples recreational catches. Data processing procedures were developed using SAS statistical software to create analysis-ready length-composition datasets for both the TIP and MRFSS databases, including creating uniform data codes for species, time, space, gears, etc., to facilitate comparative analyses among data sources (**Fig. 1.1**) with annual sample size by species included for TIP (**Table 1.2**) and MRFSS (**Table 1.3**). Maps showing bathymetric and habitat features of the coastal region of Puerto Rico along with the numbering scheme for coastal municipios are provided in **Figs. 1.2A-B**.

Table 1.1: Data sources analyzed for species length composition.

Database	Description	Years
TIP	Commercial Trip Intercepts	1983-2010
	Reconstructed, DNER Files	1988-2010
MRFSS	Sport Trip Intercepts	2000-2010
SEAMAP	Fishery-independent, trap & hook-line gears	1991-2006
NOAA BioGeo	Fishery-Independent, diver visual surveys	2000-2010

Table 1.2: Observation sample size by species and year for TIP dataset (1988-2010). Green highlighted species have sufficient length frequency data and life history data for exploitation rate analysis. Blue highlighted species have sufficient length frequency data but are lacking life history parameters.

latin	common	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Mycteroperca bonaci	black grouper	4	33	29	27	15	11	1	16	7	.	2	6
Cephalopholis fulva	coney	540	362	212	1203	1101	559	126	188	98	71	225	232
Epinephelus itajara	goliath grouper	2	8	10	1	7	6	1	.	1	.	.	1
Cephalopholis cruentata	graysby	70	92	208	217	274	102	74	54	5	30	8	26
Epinephelus mystacinus	misty grouper	7	2	2	4	9	5	.	.	.	.	1	.
Epinephelus striatus	Nassau grouper	25	25	30	52	45	6	11	4	6	.	7	13
Epinephelus morio	red grouper	2	.	2	1	4	2	.	.	.	1	.	5
Epinephelus guttatus	red hind	740	496	548	1124	783	427	352	330	119	195	517	874
Epinephelus adscensionis	rock hind	102	79	27	48	6	17	.	4	10	3	6	10
Mycteroperca tigris	tiger grouper	2	5	.	48	.	.	35	838	598	400	445	55
Mycteroperca venenosa	yellowfin grouper	13	15	8	5	4	3	1	6	.	14	2	11
Mycteroperca interstitialis	yellowmouth grouper	1	2	1	2	1	.	.	.	.	.	.	.
Apsilus dentatus	black snapper	.	2	19	.	1	.	.	.	.	.	2	6
Lutjanus buccanella	blackfin snapper	65	96	116	404	135	89	58	16	37	.	62	57
Lutjanus cyanopterus	cubera snapper	14	17	9	77	70	49	26	50	9	.	.	.
Lutjanus jocu	dog snapper	110	29	36	88	76	54	40	42	5	3	23	62
Lutjanus griseus	gray snapper	125	37	9	40	9	.	60	6	.	.	38	5
Lachnolaimus maximus	hogfish	180	219	198	237	185	104	77	76	63	46	113	245
Lutjanus synagris	lane snapper	1011	1747	1596	2449	2421	716	472	691	174	193	444	876
Lutjanus mahogoni	mahogany snapper	40	12	9	165	193	142	104	65	10	5	33	48
Lutjanus analis	mutton snapper	143	137	195	386	367	167	205	108	21	39	187	214
Etelis oculatus	queen snapper	120	495	278	315	98	46	2	3	96	4	52	111
Lutjanus apodus	schoolmaster	156	122	185	353	250	138	176	203	41	34	188	334
Lutjanus vivanus	silk snapper	658	488	547	1684	608	391	544	279	295	156	398	731
Rhomboplites aurorubens	vermilion snapper	624	276	543	2464	1025	1112	402	68	2	70	143	180
Pristipomoides aquilonaris	wenchman	45	75	71	114	39	19	12	.	20	10	8	16
Ocyurus chrysurus	yellowtail snapper	1115	656	1381	7845	7040	5021	3821	3767	496	574	1742	2062
Scarus coeruleus	blue parrotfish	.	5	6	.	5	3	.	3	5	1	11	1
Scarus coelestinus	midnight parrotfish	4	1	2	.	1	.	.	.	.	2	.	3
Scarus taeniopterus	princess parrotfish	19	43	43	80	65	37	22	10	3	.	9	35
Scarus vetula	queen parrotfish	38	33	78	20	58	40	.	.	1	17	16	65
Scarus guacamaia	rainbow parrotfish	.	6	6	4	1	.	.	.	7	1	.	5
Sparisoma aurofrenatum	redband parrotfish	34	33	50	33	21	13	26	.	.	2	8	14
Sparisoma rubripinne	yellowtail parrotfish	5	.	14	.	.	.	.	.	.	.	.	1
Sparisoma chrysopterum	redtail parrotfish	374	421	557	626	404	419	227	257	326	175	503	812
Sparisoma viride	stoplight parrotfish	649	456	729	767	587	471	264	191	323	215	570	908

Table 1.2: Cont.

latin	common	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	total	Last 3 Years
Mycteroperca bonaci	black grouper	4	2	1	8	2	.	1	.	.	6	1	25	7
Cephalopholis fulva	coney	182	439	275	301	236	81	60	19	110	121	44	1868	275
Epinephelus itajara	goliath grouper	.	6	1	3	1	.	.	.	.	.	.	11	0
Cephalopholis cruentata	graysby	9	81	23	20	23	12	11	25	6	37	20	267	63
Epinephelus mystacinus	misty grouper	1	1	4	1	11	8	11	4	7	5	.	53	12
Epinephelus striatus	Nassau grouper	7	19	4	3	9	1	.	.	.	.	1	44	1
Epinephelus morio	red grouper	.	3	1	3	.	2	2	.	1	2	.	14	3
Epinephelus guttatus	red hind	736	980	842	928	991	684	837	408	699	600	756	8461	2055
Epinephelus adscensionis	rock hind	9	3	11	10	.	2	.	1	.	1	.	37	1
Mycteroperca tigris	tiger grouper	21	21	1	5	101	18	1	.	.	.	.	168	0
Mycteroperca venenosa	yellowfin grouper	38	3	4	2	1	1	5	1	4	6	1	66	11
Mycteroperca interstitialis	yellowmouth grouper	.	.	1	1	.	1	1	.	.	.	.	4	0
Apsilus dentatus	black snapper	.	.	.	.	1	1	.	.	.	23	.	25	23
Lutjanus buccanella	blackfin snapper	118	110	56	111	241	171	139	179	185	216	155	1681	556
Lutjanus cyanopterus	cubera snapper	.	1	1	2	3	1	3	15	24	36	5	91	65
Lutjanus jocu	dog snapper	41	55	58	57	48	61	73	120	103	106	57	779	266
Lutjanus griseus	gray snapper	11	8	8	2	7	5	16	62	86	78	35	318	199
Lachnolaimus maximus	hogfish	217	421	175	182	147	162	166	92	93	333	264	2252	690
Lutjanus synagris	lane snapper	476	1277	1344	737	1342	424	862	1167	675	2017	1809	12130	4501
Lutjanus mahogoni	mahogany snapper	44	39	29	28	29	21	26	15	10	16	16	273	42
Lutjanus analis	mutton snapper	267	238	399	521	331	226	496	328	168	216	189	3379	573
Etelis oculatus	queen snapper	193	160	214	288	411	558	610	163	357	347	291	3592	995
Lutjanus apodus	schoolmaster	196	127	153	123	117	121	152	61	179	308	367	1904	854
Lutjanus vivanus	silk snapper	1522	2397	1473	1841	2118	733	1217	949	1546	1431	662	15889	3639
Rhomboplites aurorubens	vermilion snapper	161	268	251	128	181	118	96	149	210	281	107	1950	598
Pristipomoides aquilonaris	wenchman	2	21	3	10	40	44	64	55	179	69	39	526	287
Ocyurus chrysurus	yellowtail snapper	4063	2800	3630	4310	2396	2164	2663	3265	2483	2782	2005	32561	7270
Scarus coeruleus	blue parrotfish	3	.	.	.	.	.	2	.	.	1	.	6	1
Scarus coelestinus	midnight parrotfish	.	1	.	.	.	.	.	1	.	.	.	2	0
Scarus taeniopterus	princess parrotfish	107	224	83	29	63	64	62	10	34	89	41	806	164
Scarus vetula	queen parrotfish	76	146	86	62	117	48	70	12	26	37	45	725	108
Scarus guacamaia	rainbow parrotfish	1	13	1	5	.	3	1	2	5	6	1	38	12
Sparisoma aurofrenatum	redband parrotfish	1	5	1	7	5	11	9	.	.	9	.	48	9
Sparisoma rubripinne	yellowtail parrotfish	46	10	4	19	21	20	22	.	20	5	.	167	25
Sparisoma chrysopterum	redtail parrotfish	787	856	1014	696	429	419	497	97	256	242	301	5594	799
Sparisoma viride	stoplight parrotfish	993	986	1137	570	814	859	610	224	441	506	377	7517	1324

Table 1.2: Cont.

latin	common	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Conodon nobilis	barred grunt	.	196	49	1	1	.	.	.	.	.	.	.
Haemulon bonariense	black grunt	3	1	3	1	.	.	.	.	.	.	.	.
Anisostremus surinamensis	black margate	20	4	21	23	9	6	2	.	1	1	4	9
Haemulon sciurus	bluestriped grunt	638	235	267	463	61	75	79	99	53	25	193	252
Pomadasys crocro	burro grunt	.	.	1	.	.	.	.	.	.	.	.	1
Haemulon carbonarium	ceasar grunt	44	1	17	13	167	110	.	14	.	.	5	.
Haemulon flavolineatum	French grunt	43	8	9	35	9	16	8	50	13	11	30	94
Haemulon album	margate	12	16	8	20	6	15	4	3	3	2	6	11
Anisotremus virginicus	porkfish	138	89	61	33	28	22	7	20	10	7	42	31
Haemulon parra	sailors choice	127	90	61	31	1	2	.	.	.	.	5	21
Haemulon chrysargyreum	smallmouth grunt	1	11	2	6	3	1	.	1	.	.	.	.
Haemulon macrostomum	Spanish grunt	46	7	9	13	.	.	.	.	.	.	.	.
Haemulon aurolineatum	tomtate	60	38	23	61	80	46	8	20	.	.	.	.
Haemulon plumierii	white grunt	2478	2213	1908	3045	2701	1838	669	1391	218	249	921	1159
Paranthias furcifer	Atlantic creolefish	2	6	10	1	.	1	.	2	.	.	.	.
Chaetodipterus faber	Atlantic spadefish	6	14	1	1	3	.	.	3	.	.	.	.
Caranx ruber	bar jack	167	150	189	166	180	88	28	30	74	71	382	285
Kyphosus sectatrix	Bermuda chub	.	.	.	.	.	.	.	.	.	.	8	5
Priacanthus arenatus	bigeye	1	.	.	18	48	26	2	2	.	.	9	3
Melichthys niger	black durgon	.	.	.	.	8	1	.	9	1	.	.	.
Caranx lugubris	black jack	.	25	34	2	.	.	.	.	1	.	.	.
Myripristis jacobus	blackbar soldierfish	2	.	.	1	38	18	4	7	.	.	.	1
Caranx crysos	blue runner	52	57	100	91	66	182	50	24	2	.	25	17
Acanthurus coeruleus	blue tang	4	.	.	3	.	.	.	.	.	.	.	.
Fistularia tabacaria	bluespotted cornetfish	.	.	.	4	.	.	.	.	.	.	.	.
Chromis multilineata	brown chromis	.	.	1	.	2	.	.	.	.	.	2	.
Caranx hippos	crevalle jack	24	61	13	47	3	.	.	.	2	1	1	1
Acanthurus chirurgus	doctorfish	10	.	.	.	.	.	.	.	8	.	.	.
Pomacanthus paru	French angelfish	5	3	.	.	1	.	.	.	4	.	1	.
Pomacanthus arcuatus	gray angelfish	3	2	1	1	4	.	.	.	7	.	15	8
Balistes capriscus	gray triggerfish	.	.	.	.	2	.	.	.	.	.	4	10
Sphyraena barracuda	great barracuda	4	5	2	4	5	2	.	.	.	.	4	.
Sphyraena guachancho	guaguanche	.	.	3	27	43	20	1	.	.	.	.	.
Acanthostracion polygonia	honeycomb cowfish	74	49	86	65	62	90	35	18	.	10	67	45
Caranx latus	horse-eye jack	38	7	51	56	79	27	19	29	5	3	14	60
Calamus bajonado	jolthead porgy	147	199	314	285	136	238	115	59	33	31	38	95

Table 1.2: Cont.

latin	common	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	total	Last 3 Years
Conodon nobilis	barred grunt	10	3	.	.	.	3	.	23	.	.	.	39	0
Haemulon bonariense	black grunt	.	.	.	.	.	.	.	.	.	.	.	0	0
Anisostremus surinamensis	black margate	10	7	2	3	2	5	7	.	1	5	5	47	11
Haemulon sciurus	bluestriped grunt	242	541	305	294	318	504	386	112	164	207	297	3370	668
Pomadasys crocro	burro grunt	5	16	.	.	.	.	.	.	.	.	1	22	1
Haemulon carbonarium	ceasar grunt	14	7	.	4	30	3	29	.	.	7	.	94	7
Haemulon flavolineatum	French grunt	94	51	37	47	29	24	24	3	2	19	6	336	27
Haemulon album	margate	9	34	7	9	3	26	.	10	1	40	4	143	45
Anisotremus virginicus	porkfish	75	76	62	38	30	71	33	22	10	27	39	483	76
Haemulon parra	sailors choice	16	15	46	19	9	5	17	2	10	15	.	154	25
Haemulon chrysargyreum	smallmouth grunt	.	.	3	.	.	.	4	.	.	.	.	7	0
Haemulon macrostomum	Spanish grunt	.	.	.	.	.	.	.	.	.	19	249	268	268
Haemulon aurolineatum	tomtate	.	.	8	.	.	1	3	.	.	.	1	13	1
Haemulon plumierii	white grunt	1363	1359	1554	1240	789	689	669	263	248	612	628	9414	1488
Paranthias furcifer	Atlantic creolefish	.	.	.	.	.	.	.	.	.	.	.	0	0
Chaetodipterus faber	Atlantic spadefish	.	.	.	.	.	.	.	.	.	1	.	1	1
Caranx ruber	bar jack	562	415	458	390	244	106	415	202	243	206	176	3417	625
Kyphosus sectatrix	Bermuda chub	.	1	.	.	.	.	13	.	1	4	.	19	5
Priacanthus arenatus	bigeye	3	.	.	.	11	.	4	.	21	.	.	39	21
Melichthys niger	black durgon	20	.	12	.	.	4	4	.	.	.	3	43	3
Caranx lugubris	black jack	.	.	.	.	.	.	.	.	2	2	.	4	4
Myripristis jacobus	blackbar soldierfish	.	.	.	.	.	.	1	.	.	.	.	1	0
Caranx crysos	blue runner	.	.	11	27	276	144	80	42	41	132	13	766	186
Acanthurus coeruleus	blue tang	1	.	.	.	.	10	77	.	11	3	.	102	14
Fistularia tabacaria	bluespotted cornetfish	.	.	8	.	2	.	.	.	.	.	.	10	0
Chromis multilineata	brown chromis	.	.	.	.	.	.	.	.	.	.	.	0	0
Caranx hippos	crevalle jack	5	6	.	.	24	1	.	.	.	1	.	37	1
Acanthurus chirurgus	doctorfish	.	.	.	.	.	30	41	.	14	30	1	116	45
Pomacanthus paru	French angelfish	.	8	.	3	2	2	10	.	1	.	.	26	1
Pomacanthus arcuatus	gray angelfish	3	29	1	.	.	6	.	.	11	8	.	58	19
Balistes capriscus	gray triggerfish	.	83	.	.	20	.	.	.	.	1	.	104	1
Sphyraena barracuda	great barracuda	.	1	.	.	3	1	1	.	.	.	.	6	0
Sphyraena guachancho	guaguanche	.	.	.	.	.	9	8	.	21	1	.	39	22
Acanthostracion polygonia	honeycomb cowfish	35	34	19	83	97	77	81	33	27	61	38	585	126
Caranx latus	horse-eye jack	18	51	7	14	43	32	16	25	14	31	1	252	46
Calamus bajonado	jolthead porgy	59	165	123	128	50	91	131	72	43	20	6	888	69

Table 1.2: Cont.

latin	common	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Holocentrus rufus	longspine squirrelfish	1	8	1	19	72	31	.	2	.	3	.	.
Alphestes afer	mutton hamlet	16	18	1	4	1	1	.	.	1	2	.	1
Acanthurus bahianus	ocean surgeon	2	.	1	.	3	.	3	.	7	1	17	20
Canthidermis sufflamen	ocean triggerfish	5	.	.	1	1	.	.	5	.	1	.	3
Cantherhines pullus	orangespotted filefish	3	.	.	.	.	.	.	.	.	.	.	1
Calamus pennatula	pluma porgy	548	75	85	429	189	70	68	36	64	68	237	276
Halichoeres radiatus	puddingwife	16	11	1	28	19	6	3	2	.	.	.	1
Holacanthus ciliaris	queen angelfish	2	1	.	.	.	.	1	.	.	.	7	34
Balistes vetula	queen triggerfish	318	174	104	317	255	171	99	114	47	44	185	230
Elagatis bipinnulata	rainbow runner	5	9	1	2	.	1	6	.	.	.	.	1
Odontoscion dentex	reef croaker	10	15	4	4	3	1	.	2	.	.	20	276
Synodus intermedius	sand diver	.	.	.	1	1	.	1	.	.	.	.	.
Malacanthus plumieri	sand tilefish	8	.	.	.	.	.	.	.	1	.	2	2
Acanthostracion quadricornis	scrawled cowfish	295	64	36	308	113	83	36	44	11	26	105	64
Aluterus scriptus	scrawled filefish	.	3	.	.	.	.	.	.	.	.	.	.
Calamus penna	sheepshead porgy	59	11	.	2	.	.	.	.	.	.	2	.
Lagocephalus laevigatus	smooth puffer	.	.	.	1	.	.	.	.	.	.	1	.
Lactophrys triqueter	smooth trunkfish	50	19	21	102	42	50	17	11	7	6	28	23
Sphyraena picudilla	southern sennet	1	18	.	39	50	1	.	.	1	1	5	36
Bodianus rufus	Spanish hogfish	11	6	8	11	8	5	4	2	2	1	.	6
Equetus punctatus	spotted drum	.	.	.	.	.	.	.	.	3	.	.	.
Pseudupeneus maculatus	spotted goatfish	474	534	428	216	177	264	217	65	19	59	333	224
Lactophrys bicaudalis	spotted trunkfish	78	42	18	100	43	40	15	9	2	5	66	18
Holocentrus adscensionis	squirrelfish	35	1	12	312	442	152	50	70	11	.	3	49
Serranus phoebe	tattler	.	.	.	.	.	.	.	.	.	3	5	.
Lactophrys trigonus	trunkfish	3	7	.	20	47	8	2	8	.	5	1	3
Cantherhines macrocerus	whitespotted filefish	.	2	1	2	.	5	.	.	.	.	.	2
Kyphosus incisor	yellow chub	.	1	1	.	1	2	.	.	.	.	.	.
Mulloidichthys martinicus	yellow goatfish	140	101	87	81	75	43	39	27	34	18	37	26
Caranx bartholomaei	yellow jack	30	14	95	36	16	6	2	.	41	1	10	35
Alectis ciliaris	African pompano	1	9	5	7	1	5	.	.	2	.	.	2
Megalops atlanticus	tarpon	3	6	22	14	.	.	.	.	.	.	.	21
Albula vulpes	bonefish	5	1	4	7	2	3	.	.	.	.	.	.
Trachinotus falcatus	permit	13	18	5	7	5	2	20	2	19	.	.	3
Seriola rivoliana	almaco jack	2	.	10	.	.	.	.	.	.	.	.	.
Scomberomorus regalis	cero	57	193	177	196	419	85	134	104	38	31	280	180
Seriola dumerili	greater amberjack	5	9	6	10	8	6	2	1	2	.	2	2
Scomberomorus cavalla	king mackerel	91	48	180	372	107	275	77	144	46	156	92	180

Table 1.2: Cont.

latin	common	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	total	Last 3 Years
Holocentrus rufus	longspine squirrelfish	1	.	.	.	.	15	.	.	.	.	.	16	0
Alphestes afer	mutton hamlet	.	.	.	4	.	.	2	.	1	7	.	14	8
Acanthurus bahianus	ocean surgeon	22	6	11	14	7	2	.	.	.	.	.	62	0
Canthidermis sufflamen	ocean triggerfish	1	.	.	1	1	6	4	2	2	16	.	33	18
Cantherhines pullus	orangespotted filefish	.	.	.	.	.	.	7	.	.	.	1	8	1
Calamus pennatula	pluma porgy	228	710	351	423	294	178	483	87	199	77	50	3080	326
Halichoeres radiatus	puddingwife	.	.	.	.	.	1	3	1	.	.	2	7	2
Holacanthus ciliaris	queen angelfish	25	14	32	26	9	2	.	.	.	2	.	110	2
Balistes vetula	queen triggerfish	186	160	212	218	220	295	319	128	219	208	282	2447	709
Elagatis bipinnulata	rainbow runner	2	4	54	2	19	4	21	1	1	12	.	120	13
Odontoscion dentex	reef croaker	.	83	8	58	35	3	5	33	70	119	2	416	191
Synodus intermedius	sand diver	.	8	.	.	.	.	.	.	.	.	.	8	0
Malacanthus plumieri	sand tilefish	1	12	2	8	.	2	13	8	.	.	.	46	0
Acanthostracion quadricornis	scrawled cowfish	28	60	48	45	85	88	136	37	26	28	70	651	124
Aluterus scriptus	scrawled filefish	.	.	.	.	1	.	.	.	.	.	3	4	3
Calamus penna	sheepshead porgy	.	.	.	.	.	.	.	.	.	.	.	0	0
Lagocephalus laevigatus	smooth puffer	1	.	.	.	.	.	1	.	.	.	.	2	0
Lactophrys triqueter	smooth trunkfish	6	16	4	13	11	22	56	9	11	11	38	197	60
Sphyraena picudilla	southern sennet	13	17	10	.	82	41	29	20	.	29	.	241	29
Bodianus rufus	Spanish hogfish	7	6	3	2	9	1	8	.	2	1	.	39	3
Equetus punctatus	spotted drum	1	.	.	1	.	.	.	.	.	.	.	2	0
Pseudupeneus maculatus	spotted goatfish	253	131	77	102	180	68	247	106	131	291	14	1600	436
Lactophrys bicaudalis	spotted trunkfish	11	35	11	22	30	49	49	24	18	27	26	302	71
Holocentrus adscensionis	squirrelfish	75	69	28	14	16	22	43	2	.	7	.	276	7
Serranus phoebe	tattler	.	.	.	.	.	.	.	.	.	.	.	0	0
Lactophrys trigonus	trunkfish	20	23	46	99	43	187	357	21	.	.	.	796	0
Cantherhines macrocerus	whitespotted filefish	.	.	.	.	.	.	11	1	.	.	1	13	1
Kyphosus incisor	yellow chub	.	.	.	.	.	.	.	.	.	.	.	0	0
Mulloidichthys martinicus	yellow goatfish	17	58	34	27	12	24	24	6	1	17	2	222	20
Caranx bartholomaei	yellow jack	14	95	27	25	63	27	42	36	4	7	3	343	14
Alectis ciliaris	African pompano	.	.	1	.	.	4	.	.	5	8	.	18	13
Megalops atlanticus	tarpon	.	36	11	1	10	.	.	.	.	1	1	60	2
Albula vulpes	bonefish	.	.	.	.	.	.	.	.	.	5	.	5	5
Trachinotus falcatus	permit	3	1	34	26	15	.	11	2	1	3	1	97	5
Seriola rivoliana	almaco jack	.	.	.	.	.	.	6	.	.	.	.	6	0
Scomberomorus regalis	cero	112	109	123	97	199	341	269	93	135	69	69	1616	273
Seriola dumerili	greater amberjack	4	4	.	.	5	3	3	4	2	.	.	25	2
Scomberomorus cavalla	king mackerel	799	1289	1185	416	264	373	626	211	319	272	160	5914	751

Table 1.3: Observation sample size by species and year for MRFSS dataset (2000-2010). Green highlighted species have sufficient length frequency data and life history data for exploitation rate analysis. Blue highlighted species have sufficient length frequency data but are lacking life history parameters.

latin	common	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total	Last 3 Years
Mycteroperca bonaci	black grouper	.	.	.	.	.	.	.	1	.	.	.	1	0
Cephalopholis fulva	coney	31	30	4	71	84	32	6	13	16	13	9	309	38
Epinephelus itajara	goliath grouper	3	.	1	.	.	.	.	.	.	.	.	4	0
Cephalopholis cruentata	graysby	10	4	.	3	7	2	.	1	2	2	7	38	11
Epinephelus mystacinus	misty grouper	.	.	.	.	1	.	.	.	1	.	1	3	2
Epinephelus striatus	Nassau grouper	1	.	.	6	1	.	1	1	.	.	.	10	0
Epinephelus morio	red grouper	.	.	.	.	.	1	.	1	.	.	.	2	0
Epinephelus guttatus	red hind	17	47	21	29	21	62	5	12	10	9	22	255	41
Epinephelus adscensionis	rock hind	2	1	.	.	.	.	2	3	1	1	1	11	3
Mycteroperca venenosa	yellowfin grouper	.	1	.	4	.	.	2	.	.	2	.	9	2
Apsilus dentatus	black snapper	.	1	.	.	.	.	.	.	.	.	.	1	0
Lutjanus buccanella	blackfin snapper	4	7	.	23	2	2	.	2	5	10	2	57	17
Lutjanus cyanopterus	cubera snapper	2	2	.	1	.	.	1	1	.	.	.	7	0
Lutjanus jocu	dog snapper	5	15	1	5	1	3	.	9	5	7	2	53	14
Lutjanus griseus	gray snapper	2	1	1	4	.	.	4	10	1	.	.	23	1
Lachnolaimus maximus	hogfish	.	3	.	2	.	.	.	1	.	.	2	8	2
Lutjanus synagris	lane snapper	16	26	2	36	27	18	12	41	28	4	47	257	79
Lutjanus mahogoni	mahogany snapper	2	.	.	.	.	.	.	2	.	1	1	6	2
Lutjanus analis	mutton snapper	11	8	8	23	24	16	9	18	12	8	12	149	32
Etelis oculatus	queen snapper	2	14	19	12	8	17	2	9	9	1	7	100	17
Lutjanus apodus	schoolmaster	6	10	1	18	5	8	6	5	3	1	6	69	10
Lutjanus vivanus	silk snapper	52	54	18	56	42	38	11	26	21	25	9	352	55
Rhomboplites aurorubens	vermilion snapper	15	10	16	5	1	3	.	11	6	1	11	79	18
Pristipomoides aquilonaris	wenchman	3	12	6	25	8	11	.	20	3	4	3	95	10
Ocyurus chrysurus	yellowtail snapper	14	19	21	31	39	19	8	15	22	22	18	228	62
Conodon nobilis	barred grunt	.	.	.	.	1	.	.	.	.	.	.	1	0
Anisostremus surinamensis	black margate	4	3	3	13	.	.	.	.	.	2	.	25	2
Haemulon sciurus	bluestriped grunt	9	6	.	2	.	.	.	2	1	.	.	20	1
Haemulon carbonarium	ceasar grunt	1	6	.	1	.	1	.	.	.	.	.	9	0
Haemulon flavolineatum	French grunt	2	.	1	1	1	.	.	.	.	.	.	5	0
Haemulon album	margate	.	.	.	.	.	.	.	.	1	.	1	2	2
Anisotremus virginicus	porkfish	1	1	1	2	.	1	.	.	.	2	.	8	2
Haemulon parra	sailors choice	2	.	.	6	1	.	.	1	.	3	.	13	3
Haemulon chrysargyreum	smallmouth grunt	.	.	2	2	.	.	.	.	.	.	.	4	0
Haemulon macrostomum	Spanish grunt	.	1	.	1	.	1	1	.	.	.	.	4	0
Haemulon aurolineatum	tomtate	1	.	.	2	7	.	2	.	.	.	1	13	1
Haemulon plumierii	white grunt	10	14	8	9	5	3	3	2	.	3	5	62	8
Scarus coeruleus	blue parrotfish	2	.	.	.	.	.	.	.	.	.	.	2	0
Scarus taeniopterus	princess parrotfish	.	.	.	2	.	2	.	.	1	.	.	5	1
Scarus vetula	queen parrotfish	2	4	2	.	.	.	.	.	.	2	.	10	2
Scarus guacamaia	rainbow parrotfish	.	.	.	1	.	.	.	.	.	.	.	1	0
Sparisoma aurofrenatum	redband parrotfish	.	3	.	4	1	.	.	.	.	.	.	8	0
Sparisoma rubripinne	yellowtail parrotfish	2	7	.	8	.	.	.	.	.	5	.	22	5
Sparisoma chrysopterum	redtail parrotfish	1	4	7	4	.	.	.	.	.	2	.	18	2
Sparisoma viride	stoplight parrotfish	.	19	.	15	.	.	.	6	8	15	2	65	25

Table 1.3: Cont.

latin	common	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total	Last 3 Years
Chaetodipterus faber	Atlantic spadefish	.	1	.	.	.	.	.	1	1	.	.	3	1
Caranx ruber	bar jack	4	6	14	26	5	4	2	6	6	9	1	83	16
Kyphosus sectatrix	Bermuda chub	.	1	.	1	.	.	.	.	.	1	.	3	1
Priacanthus arenatus	bigeye	.	1	.	2	1	.	.	.	.	.	.	4	0
Melichthys niger	black durgon	5	52	11	41	2	20	2	2	.	1	.	136	1
Caranx lugubris	black jack	4	8	.	2	.	.	.	.	2	6	.	22	8
Caranx crysos	blue runner	5	44	13	50	23	12	5	9	15	15	11	202	41
Acanthurus coeruleus	blue tang	.	1	.	1	.	.	.	.	.	.	.	2	0
Caranx hippos	crevalle jack	4	22	10	24	10	6	8	6	7	5	4	106	16
Acanthurus chirurgus	doctorfish	2	.	.	.	.	.	.	.	.	.	.	2	0
Pomacanthus paru	French angelfish	.	2	.	3	.	.	.	.	.	2	.	7	2
Pomacanthus arcuatus	gray angelfish	.	1	.	.	.	.	.	.	.	.	.	1	0
Balistes capriscus	gray triggerfish	11	1	.	13	4	.	.	.	.	.	.	29	0
Sphyraena barracuda	great barracuda	20	38	9	52	26	26	14	9	14	18	12	238	44
Sphyraena guachancho	guaguanche	1	.	.	.	.	.	.	2	13	12	1	29	26
Acanthostracion polygonia	honeycomb cowfish	.	1	.	1	.	.	.	.	.	.	.	2	0
Caranx latus	horse-eye jack	5	5	1	.	3	.	1	2	.	2	3	22	5
Calamus bajonado	jolthead porgy	3	.	.	.	.	.	.	2	1	.	.	6	1
Holocentrus rufus	longspine squirrelfish	1	.	.	4	.	.	.	.	2	.	.	7	2
Acanthurus bahianus	ocean surgeon	1	.	.	.	.	.	.	.	.	.	.	1	0
Canthidermis sufflamen	ocean triggerfish	12	1	.	2	1	4	.	.	.	2	.	22	2
Calamus pennatula	pluma porgy	.	1	.	18	9	4	1	1	1	.	.	35	1
Halichoeres radiatus	puddingwife	2	10	1	15	2	2	.	.	1	.	1	34	2
Balistes vetula	queen triggerfish	6	16	2	4	2	4	2	3	7	3	7	56	17
Elagatis bipinnulata	rainbow runner	1	2	.	3	.	1	.	1	5	.	1	14	6
Malacanthus plumieri	sand tilefish	.	7	3	7	6	1	.	.	.	.	.	24	0
Acanthostracion quadricornis	scrawled cowfish	.	1	.	.	.	.	.	.	.	.	.	1	0
Lactophrys triqueter	smooth trunkfish	.	2	.	1	.	1	.	.	.	.	.	4	0
Sphyraena picudilla	southern sennet	7	2	2	3	.	.	2	1	.	1	.	18	1
Bodianus rufus	Spanish hogfish	.	2	2	.	.	.	.	.	.	2	1	7	3
Pseudupeneus maculatus	spotted goatfish	1	2	.	.	2	.	.	.	.	.	.	5	0
Lactophrys bicaudalis	spotted trunkfish	.	1	.	.	.	1	1	.	.	.	.	3	0
Holocentrus adscensionis	squirrelfish	6	8	3	7	7	1	.	1	4	.	.	37	4
Lactophrys trigonus	trunkfish	2	2	2	19	18	.	1	1	.	.	.	45	0
Mulloidichthys martinicus	yellow goatfish	1	3	1	.	4	.	.	1	.	1	.	11	1
Caranx bartholomaei	yellow jack	1	8	.	1	1	2	11	3	1	3	4	35	8
Alectis ciliaris	African pompano	.	.	.	1	.	.	.	2	.	1	.	4	1
Megalops atlanticus	tarpon	2	2	.	1	3	1	.	1	2	.	.	12	2
Albula vulpes	bonefish	.	1	2	1	1	3	.	2	.	.	.	10	0
Trachinotus falcatus	permit	2	2	1	2	1	1	10	.	1	1	1	22	3
Scomberomorus regalis	cero	10	21	10	18	12	17	13	24	14	17	2	158	33
Seriola dumerili	greater amberjack	7	1	3	1	1	2	.	1	.	.	1	17	1
Scomberomorus cavalla	king mackerel	10	12	7	8	6	12	15	15	9	12	6	112	27

Figure 1.1: Database processing flow chart.

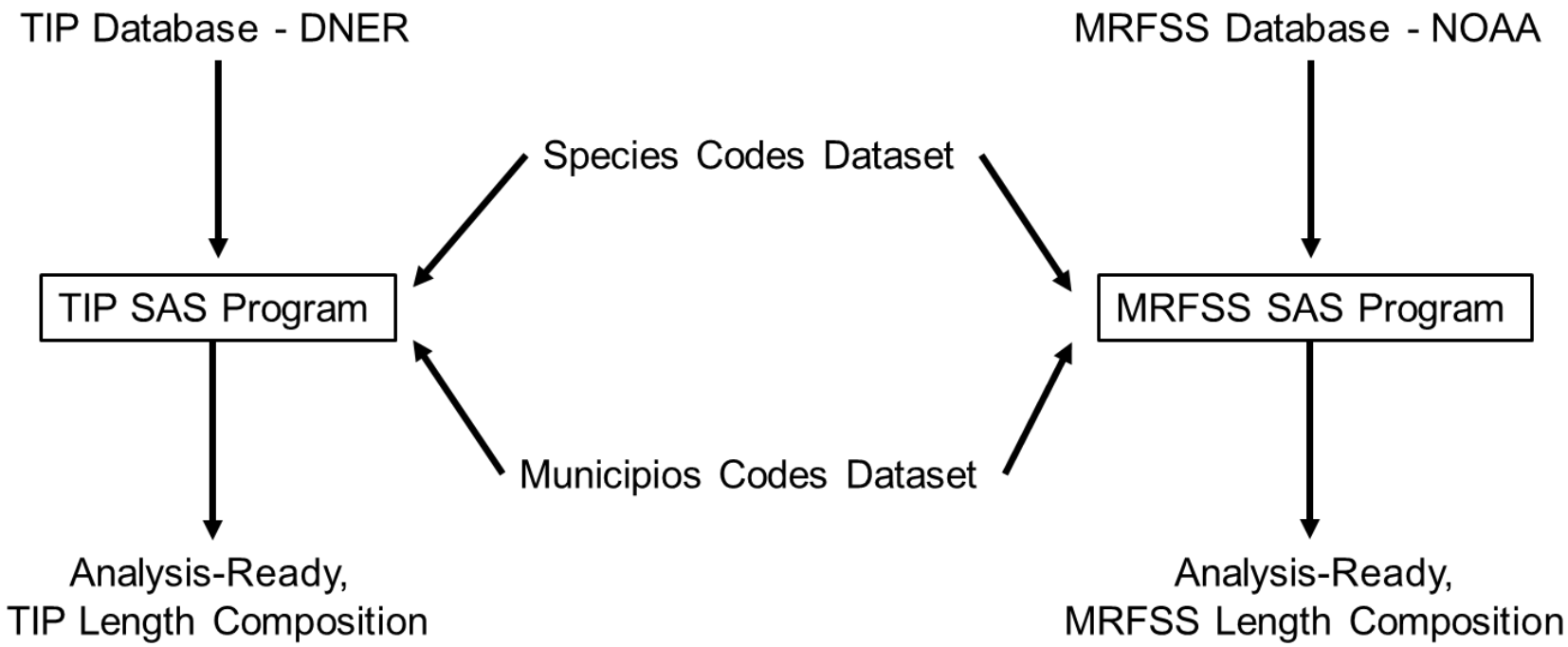
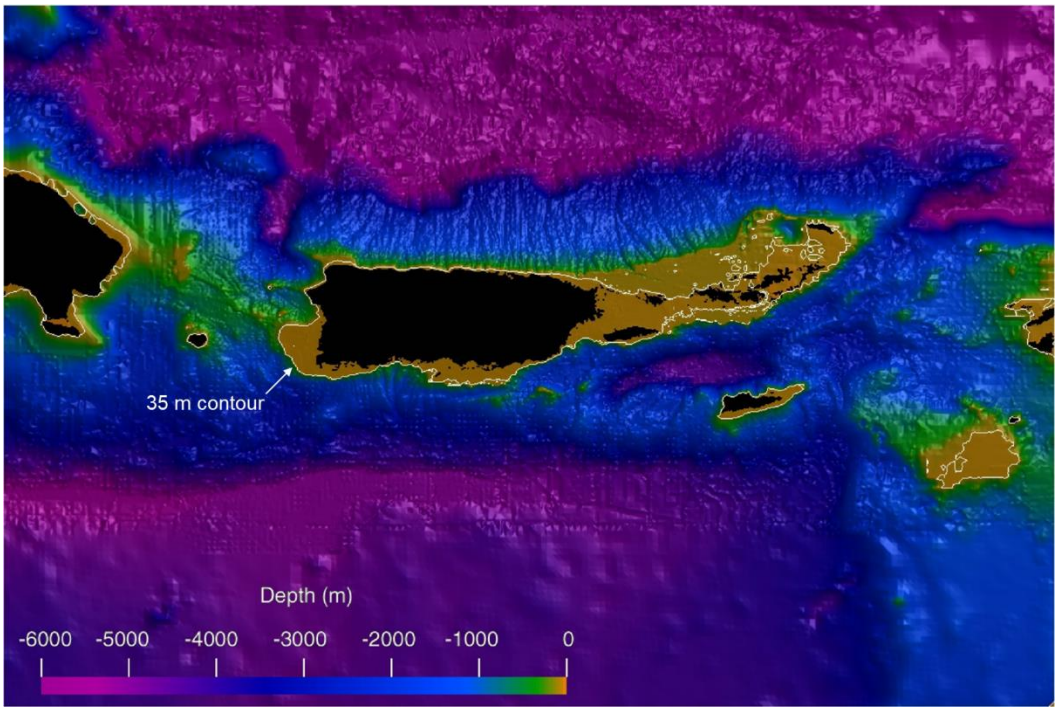


Figure 1.2: A. Bathymetry map showing the 35m contour line, **B.** Map of Puerto Rico showing the municipios and benthic habitat types.

A



B

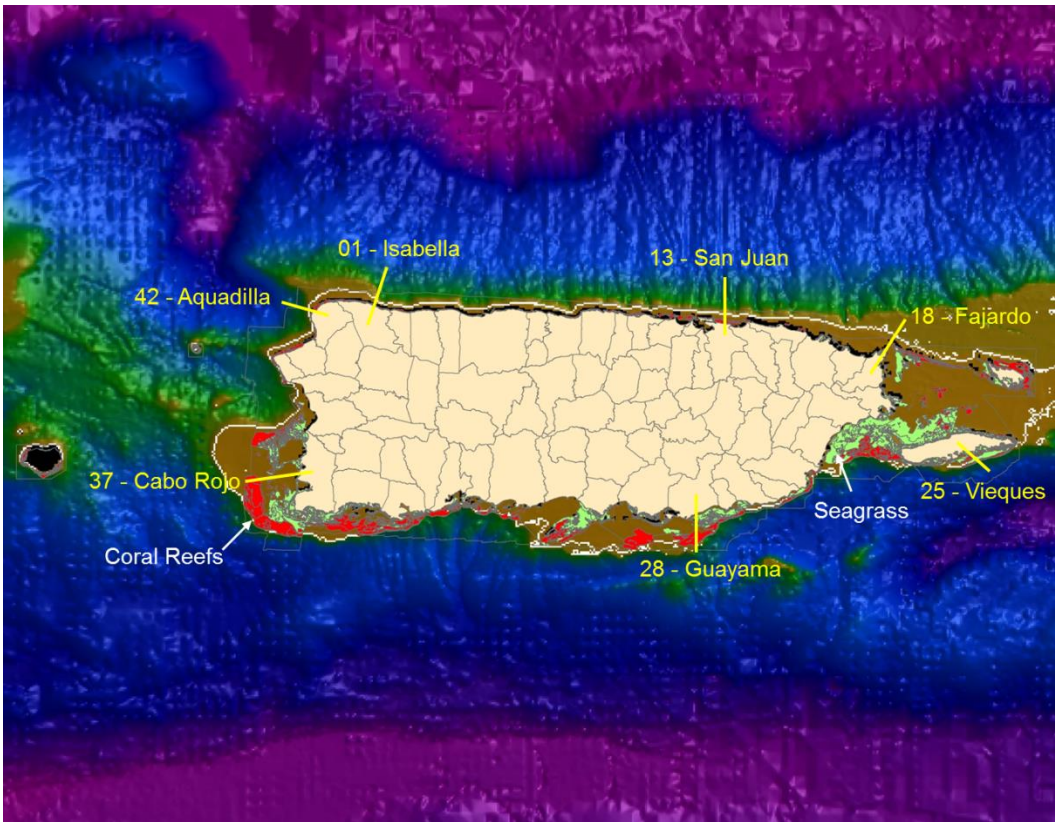
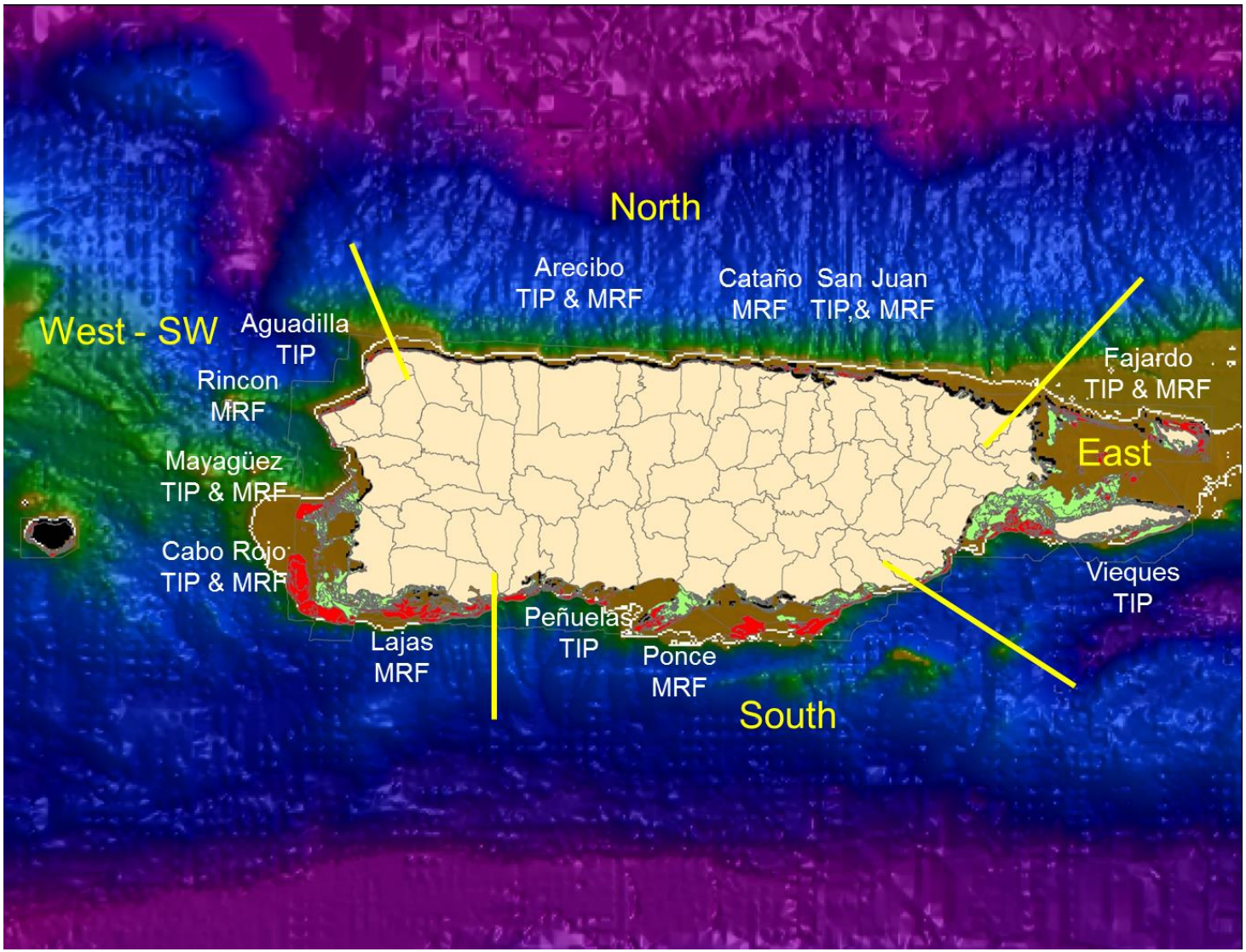


Figure 1.3: Map of Puerto Rico showing the four fishing regions and corresponding principal municipios for the different databases.



2.0 LBAR ESTIMATION METHODOLOGY

Estimation of Lbar, the average length in the exploited phase, requires designation of the minimum capture length, Lc, above which fishes are generally retained in the catch and brought back to the dock for sale, consumption, etc. In cases where fishery regulations specify a minimum legal size, Lc is set to this size. In cases where a minimum size is not regulated, Lc must be estimated from the catch data. **Figures 2.1-2.7** illustrate sample frequency distributions with Lc, Lbar, and Linf/Lmax for seven focus species: red hind, dog snapper, schoolmaster, bluestriped grunt, lane snapper, redtail parrotfish, and stoplight parrotfish. The values of Lc were calculated for all years of data, while the length frequency represents just the last three years (2008-2010) being the current status.

Exploited phase length composition data were extracted from the two main fishery-independent sampling programs, the SEAMAP program utilizing trap and bottom line gears and the NOAA Biogeography Team diver visual survey, for the reef species present in the TIP and MRFSS catch sampling. Both fishery-independent sampling programs were predominately conducted in the West-Southwest region (**Fig. 2.8**). Comparability of Lbar estimates among the various fishery-dependent and -independent sampling programs was evaluated.

Estimates of average length $\overline{L}$ were computed using the general ratio-of-means estimator

$$\hat{R} = \frac{\bar{y}}{\bar{x}} = \frac{\sum_i y_i}{\sum_i x_i} \quad , \qquad (2.1)$$

where

$\hat{R} = \overline{L}$

x_i = number of fish measured in trip i,

y_i = summed length of all fish measured in trip i.

n = number of trips,

$\bar{x} = \dfrac{\sum_i x_i}{n}$ = sample mean of number of fish measured, and

$\bar{y} = \dfrac{\sum_i y_i}{n}$ = sample mean of summed length of measured fish.

The ratio estimate $\hat{R}$ (i.e., the estimate of average length) was then used to compute the sample variance

$$s^2 = \frac{\left(y_i - \hat{R}x_i\right)^2}{n-1} \quad , \qquad (2.2)$$

variance of the estimate,

$$\mathrm{var}(\hat{R}) = \frac{s^2}{n\bar{x}^2} \quad , \qquad (2.3)$$

and standard error

$$SE(\hat{R}) = \sqrt{\mathrm{var}(\hat{R})} \quad . \quad (2.4)$$

Illustrative results of these analyses are shown in **Figures 2.1-2.7**. Red hind, lane snapper, and stoplight parrotfish Lbar estimates for the three consecutive years were comparable for the TIP and MRFSS catch sampling, and indicated no directional bias in Lbar by data source (**Figures 2.1, 2.5, 2.7**). In contrast, Lbar estimates for dog snapper were higher in TIP catch sampling compared to MRFSS catch sampling (**Figure 2.2**) suggesting a difference in selectivity patterns between the two fleets, likely due to variation in the primary gears used.

Our analyses suggest that the commercial and sport fleets in Puerto Rico are sampling the same population of a given reef fish species, and that slight differences in length composition between the two sampling programs are mostly a function of how different gears are deployed in different regions and depth ranges.

Annual estimates of Lbar based solely on the commercial fleet data, the largest and longest source of length composition data, were nearly identical to Lbar estimates using the combined data from all sources and as such were used as representative for the time-series estimates of Lbar. These were computed for all reef-fish species using the following procedure for cases with small sample sizes: (i) data were pooled for up to four consecutive years if they each contained less than 15 observations from less than 5 trips until their aggregate exceeded these thresholds; (ii) individual years with poor data were retained as independent estimates with high uncertainty, (iii) If larger blocks of time still possessed insufficient sampling the species was not considered for full time-series analysis, (iv) current status estimates were still computed if possible. Species sample sizes by year are provided for TIP (**Table 1.2**) and MRFSS (**Table 1.3**) data. Time-series estimates of Lbar for 28 reef-fish species are given in **Table 2.1**. The current status (2008-2010) Lbar estimates for 34 reef-fish species are given in **Table 2.2**.

Table 2.1: Time-series of Lbar estimates from TIP for all species with sufficient data series.

species	Common	Lc	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Cephalopholis fulvus	coney	220	247.66	248.90	245.99	250.51	250.80	252.68	256.36	255.84	256.14	254.44	256.07	256.83
Epinephelus guttatus	red hind	260	320.84	326.20	331.55	334.24	323.61	326.43	327.82	320.81	321.60	325.22	324.80	345.99
Lutjanus buccanella	blackfin snapper	220	270.52	302.20	282.33	280.14	260.59	281.22	274.24	275.96	275.96	275.96	288.50	316.67
Lutjanus jocu	dog snapper	250	339.87	416.72	393.61	374.16	391.78	369.26	386.75	327.00	429.55	429.55	429.55	396.53
Lachnolaimus maximus	hogfish	240	357.15	386.89	389.31	354.95	374.23	365.38	349.83	365.79	337.19	360.54	334.94	352.80
Lutjanus synagris	lane snapper	210	248.91	251.77	247.45	249.39	250.43	254.70	246.36	265.15	251.53	244.41	250.98	245.65
Lutjanus mahogani	mahogany snapper	250	296.78	293.19	293.19	286.62	282.18	292.45	292.60	288.03	296.87	296.87	295.85	304.60
Lutjanus analis	mutton snapper	240	363.38	392.47	374.79	420.47	417.27	468.57	389.68	426.39	398.19	349.08	457.58	335.74
Etelis oculatus	queen snapper	290	508.29	408.57	438.35	371.49	403.85	405.93	376.90	376.90	376.90	376.90	487.63	467.56
Lutjanus apodus	schoolmaster	220	293.29	295.70	304.76	293.85	303.29	301.60	322.48	324.39	320.24	350.41	278.36	278.39
Lutjanus vivanus	silk snapper	220	274.93	307.16	282.84	278.06	268.67	280.97	273.50	277.95	272.46	279.64	279.10	290.38
Rhomboplites aurorubens	vermilion snapper	200	221.42	232.16	223.92	219.71	219.63	218.94	220.19	220.35	229.00	236.31	221.50	255.43
Pristipomoides aquilonaris	wenchman	180	212.76	312.13	276.69	261.27	255.15	226.45	226.45		278.89	278.89	278.89	278.89
Ocyurus chrysurus	yellowtail snapper	240	291.07	291.91	294.96	298.41	293.03	290.17	289.36	306.29	289.84	302.19	322.04	305.75
Haemulon sciurus	bluestriped grunt	200	239.95	233.63	234.67	238.10	236.67	247.96	247.38	242.54	241.49	235.41	241.22	236.71
Anisotremus virginicus	porkfish	210	239.45	234.24	234.00	248.36	241.11	235.77	236.70	236.70	235.59	235.59	240.07	235.81
Haemulon plumieri	white grunt	200	233.27	229.53	232.68	234.19	235.25	234.03	237.00	238.61	230.59	238.98	231.52	231.84
Acanthostracion polygonia	honeycomb cowfish	200	230.92	247.24	239.12	244.83	266.71	240.74	241.74	263.86	263.86	263.86	261.60	257.56
Balistes vetula	queen triggerfish	230	292.77	284.74	282.53	292.81	294.86	296.92	295.00	272.65	296.13	274.25	299.88	343.85
Acanthostracion quadricornis	scrawled cowfish	190	227.42	228.20	238.25	218.05	231.04	229.63	241.08	231.50	242.11	242.11	228.93	238.94
Lactophrys triqueter	smooth trunkfish	150	192.86	204.89	196.05	189.36	195.00	197.46	214.82	213.50	213.50	213.50	185.71	234.83
Pseudupeneus maculatus	spotted goatfish	150	190.14	186.16	182.96	193.82	195.17	190.44	173.98	188.45	198.00	179.58	167.90	167.11
Lactophrys bicaudalis	spotted trunkfish	150	205.92	203.60	229.44	207.30	217.21	197.30	213.35	213.35	213.35	213.35	225.65	255.62
Mulloidichthys martinicus	yellow goatfish	160	214.80	212.64	198.06	205.93	213.96	212.21	211.56	223.00	225.21	202.50	197.59	220.19
Scarus taeniopterus	princess parrotfish	240	265.32	257.42	261.86	266.19	261.18	269.49	283.91	279.91	279.91	279.91	279.91	266.17
Scarus vetula	queen parrotfish	250	294.53	307.30	304.65	292.55	297.91	286.40	250.00	250.00	250.00	293.94	293.94	284.86
Sparisoma chrysopterum	redtail parrotfish	240	271.69	269.45	269.09	270.79	265.01	268.37	275.67	278.52	272.03	276.67	273.10	275.68
Sparisoma viride	stoplight parrotfish	220	285.47	275.90	279.21	279.99	273.11	273.80	275.60	293.78	283.76	280.07	275.25	278.38

Table 2.1: Cont.

species	Common	Lc	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Cephalopholis fulvus	coney	220	253.39	254.42	255.12	250.46	261.74	254.01	259.62	259.00	264.37	266.28	259.52
Epinephelus guttatus	red hind	260	338.01	329.07	327.81	343.26	345.41	346.10	353.21	344.32	355.85	352.87	344.00
Lutjanus buccanella	blackfin snapper	220	297.31	286.04	279.64	290.64	304.82	299.37	321.89	314.57	289.03	312.93	295.65
Lutjanus jocu	dog snapper	250	382.34	501.60	463.81	428.07	366.77	395.30	401.19	365.76	380.33	401.64	447.61
Lachnolaimus maximus	hogfish	240	361.81	333.21	349.82	356.61	361.39	367.81	388.89	364.64	366.29	371.14	379.65
Lutjanus synagris	lane snapper	210	257.48	265.67	257.02	282.89	261.36	274.05	264.66	268.20	268.69	272.19	277.41
Lutjanus mahogani	mahogany snapper	250	309.11	289.03	352.62	300.11	317.45	286.76	349.65	320.48	320.48	332.13	332.13
Lutjanus analis	mutton snapper	240	439.20	402.28	426.89	458.58	387.11	431.18	385.41	409.33	450.62	430.90	444.98
Etelis oculatus	queen snapper	290	408.69	474.17	499.19	463.11	452.78	509.47	468.39	469.89	458.76	458.50	443.69
Lutjanus apodus	schoolmaster	220	286.46	281.63	284.65	287.41	306.59	275.57	292.63	310.92	312.24	305.21	311.53
Lutjanus vivanus	silk snapper	220	292.17	289.82	302.76	323.87	312.26	351.74	348.11	345.23	334.90	345.95	335.18
Rhomboplites aurorubens	vermilion snapper	200	228.14	250.17	244.99	255.80	243.81	251.54	270.97	273.06	273.38	261.61	266.89
Pristipomoides aquilonaris	wenchman	180	350.81	350.81	350.81	350.81	291.13	359.57	370.25	358.49	324.42	360.22	367.54
Ocyurus chrysurus	yellowtail snapper	240	314.59	322.16	323.99	336.88	317.42	328.86	340.31	328.02	334.79	318.31	332.67
Haemulon sciurus	bluestriped grunt	200	233.03	233.37	234.01	235.00	234.19	235.69	236.86	247.87	240.56	245.43	242.64
Anisotremus virginicus	porkfish	210	252.88	233.88	234.65	235.95	237.17	236.80	242.15	237.31	237.31	241.11	232.90
Haemulon plumieri	white grunt	200	239.24	235.17	236.66	235.71	231.01	230.47	237.30	269.25	252.00	251.00	252.56
Acanthostracion polygonia	honeycomb cowfish	200	259.46	243.03	257.53	254.95	257.33	260.27	251.56	266.58	260.85	244.08	261.97
Balistes vetula	queen triggerfish	230	336.20	298.06	324.91	353.04	361.32	306.05	303.22	331.87	337.74	317.47	293.44
Acanthostracion quadricornis	scrawled cowfish	190	241.50	243.32	257.04	264.93	265.20	255.88	242.43	269.78	271.12	255.36	237.39
Lactophrys triqueter	smooth trunkfish	150	175.38	175.38	175.38	214.00	214.00	221.36	194.45	206.13	206.13	206.13	201.68
Pseudupeneus maculatus	spotted goatfish	150	173.99	180.97	175.81	178.35	186.37	204.59	179.37	178.90	185.92	193.60	190.86
Lactophrys bicaudalis	spotted trunkfish	150	255.62	236.74	236.42	236.42	242.87	255.39	251.67	260.00	286.28	262.19	261.08
Mulloidichthys martinicus	yellow goatfish	160	215.00	210.79	199.59	222.81	242.92	209.00	220.79	221.12	221.12	221.12	221.12
Scarus taeniopterus	princess parrotfish	240	258.89	258.09	263.64	272.48	261.71	263.83	263.45	283.10	254.09	258.70	272.27
Scarus vetula	queen parrotfish	250	292.67	299.39	302.01	302.71	296.81	296.27	306.63	296.63	296.63	294.27	299.78
Sparisoma chrysopterum	redtail parrotfish	240	277.95	277.48	282.72	280.40	273.14	269.75	276.37	290.00	279.32	272.21	273.04
Sparisoma viride	stoplight parrotfish	220	276.35	275.95	279.35	280.77	270.87	283.15	277.46	289.73	272.79	272.58	286.66

Table 2.2: Current status (2008-2010) Lbar estimates for all species with sufficient sample data from both the TIP and MRFSS surveys.

Complex	species	common	a+	L_C	L_{max}	Lbar TIP	Lbar MRFSS
Groupers	*Cephalopholis fulvus*	**Coney**	17	220	648.10	255.41	275.87
Groupers	*Epinephelus cruentatus*	**Graysby**	15	200	362.75	262.18	
Groupers	*Epinephelus guttatus*	**Red Hind**	17	260	461.66	344.29	336.54
Snappers	*Lutjanus buccanella*	**Blackfin**	9	220	460.10	297.42	293.53
Snappers	*Lutjanus cyanopterus*	**Cubera**	25	240	1179.05	617.00	
Snappers	Lutjanus jocu	**Dog**	20	250	759.37	399.43	344.21
Snappers	Lutjanus griseus	**Gray**	28	240	708.05	334.21	
Snappers	Lachnolaimus maximus	**Hogfish**	23	240	786.21	368.09	
Snappers	Lutjanus synagris	**Lane**	19	210	534.82	269.78	266.97
Snappers	Lutjanus mahogani	**Mahogony**	10	250	420.08	299.60	
Snappers	Lutjanus analis	**Mutton**	29	240	918.49	435.20	433.13
Snappers	Lutjanus apodus	**Schoolmaster**	12	220	504.26	303.45	
Snappers	*Lutjanus vivanus*	**Silk**	9	220	505.13	332.66	337.15
Snappers	Rhomboplites aurorubens	**Vermilion**	14	200	566.35	253.99	235.06
Snappers	*Ocyurus chrysurus*	**Yellowtail**	14	240	451.22	324.17	314.32
Grunts	*Haemulon sciurus*	**Bluestriped**	8	200	375.53	240.34	
Grunts	*Haemulon flavolineatum*	**French**	12	190	259.69	200.82	
Grunts	*Haemulon album*	**Margate**	20	210	731.16	316.63	
Grunts	*Anisotremus virginicus*	**Porkfish**	7	210	381.36	225.28	
Grunts	*Haemulon plumieri*	**White**	18	200	496.25	250.01	
Other Reef Fishes	*Caranx ruber*	**Bar Jack**	20	250	515.72	313.09	316.63
Other Reef Fishes	*Caranx crysos*	**Blue Runner**	11	220	687.40	357.63	295.49
Other Reef Fishes	*Caranx hippos*	**Crevalle Jack**	18	190	1207.11		520.50
Other Reef Fishes	*Acanthurus chirurgus*	**Doctorfish**	11	180	314.69	202.43	
Other Reef Fishes	*Sphyraena barracuda*	**Great Barracuda**	32	350	1690.23		647.73
Other Reef Fishes	*Caranx latus*	**Horse-eye Jack**	12	320	784.97	461.70	
Other Reef Fishes	*Calamus bajonado*	**Jolthead Porgy**	13	180	668.51	253.44	
Other Reef Fishes	*Balistes vetula*	**Queen Triggerfish**	13	230	725.52	309.13	337.53
Parrotfish	*Scarus taeniopterus*	**Princess**	6	240	348.30	255.00	
Parrotfish	*Scarus vetula*	**Queen**	5	250	527.10	291.76	
Parrotfish	*Sparisoma chrysopterum*	**Redtail**	8	240	440.00	270.28	
Parrotfish	*Sparisoma viride*	**Stoplight**	12	220	600.23	274.90	271.00
Pelagics	*Scomberomorus regalis*	**Cero**	17	380	1770.13	481.97	529.91
Pelagics	*Scomberomorus cavalla*	**King Mackerel**	19.3	450	1302.30	775.23	798.00

Figure 2.1: Length frequency data (TIP, 2008-2010), bounding Lc-Lmax range, and calculated Lbar (TIP & MRFSS, 2008-2010) for red hind.

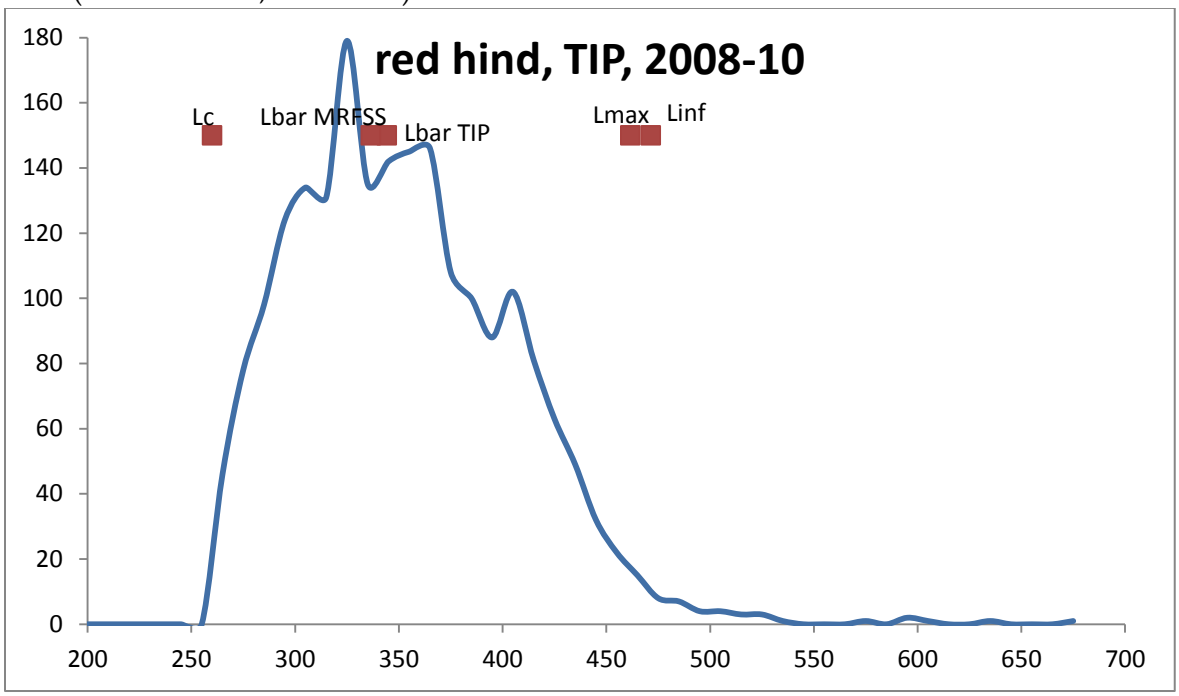


Figure 2.2: Length frequency data (TIP, 2008-2010), bounding Lc-Lmax range, and calculated Lbar (TIP & MRFSS, 2008-2010) for dog snapper.

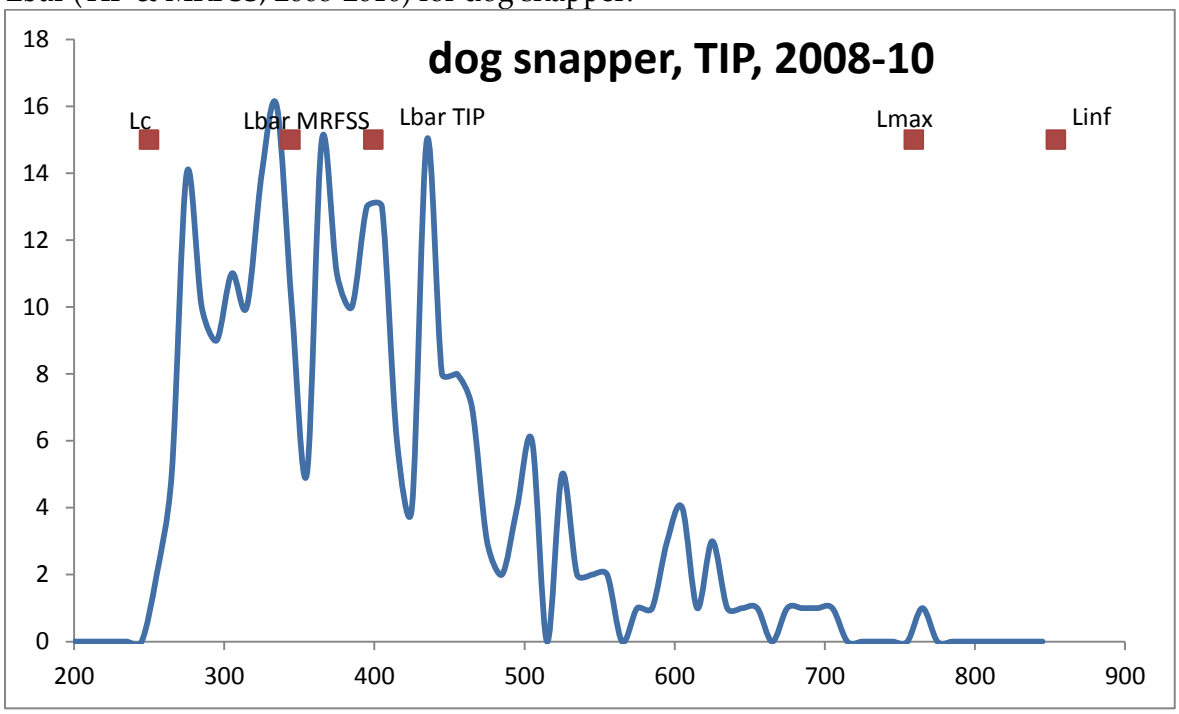


Figure 2.3: Length frequency data (TIP, 2008-2010), bounding Lc-Lmax range, and calculated Lbar (TIP, 2008-2010) for schoolmaster.

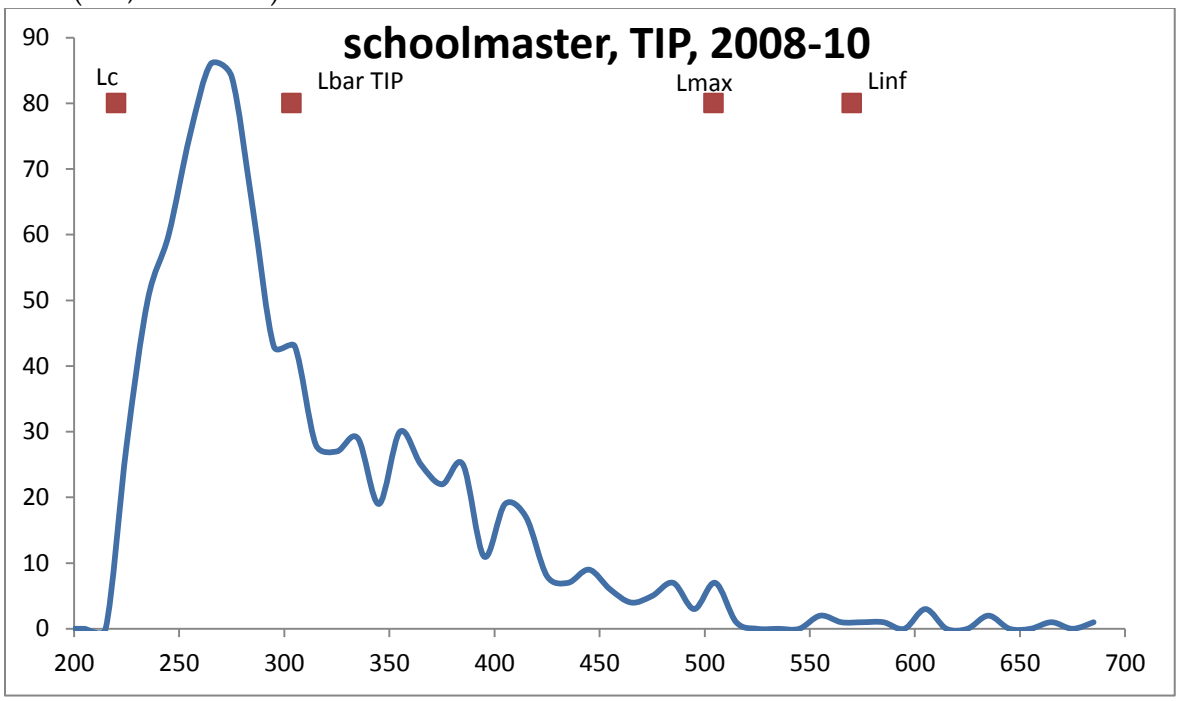


Figure 2.4: Length frequency data (TIP, 2008-2010), bounding Lc-Lmax range, and calculated Lbar (TIP, 2008-2010) for bluestriped grunt.

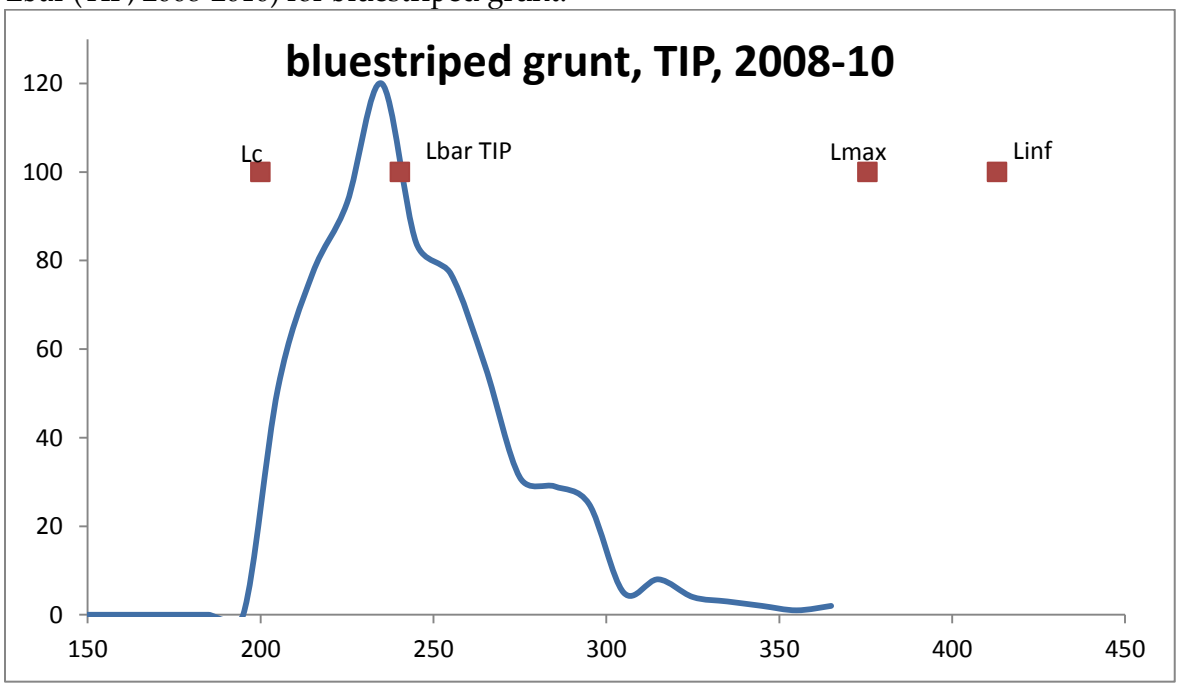


Figure 2.5: Length frequency data (TIP, 2008-2010), bounding Lc-Lmax range, and calculated Lbar (TIP & MRFSS, 2008-2010) for lane snapper.

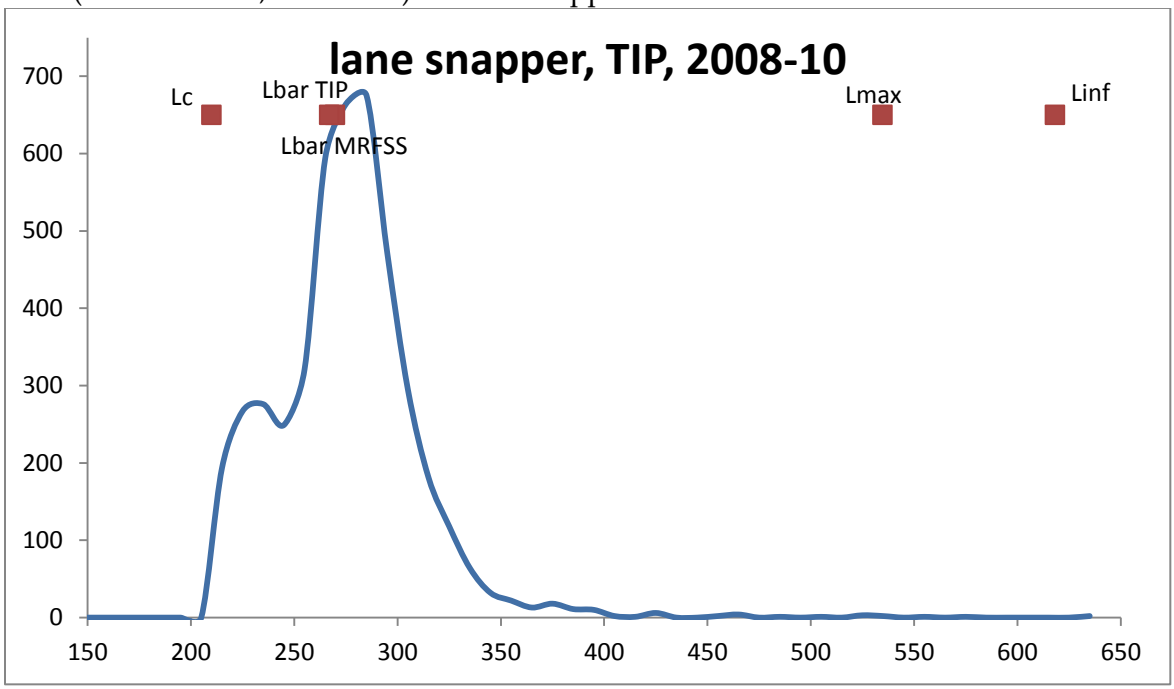


Figure 2.6: Length frequency data (TIP, 2008-2010), bounding Lc-Lmax range, and calculated Lbar (TIP, 2008-2010) for redtail parrotfish.

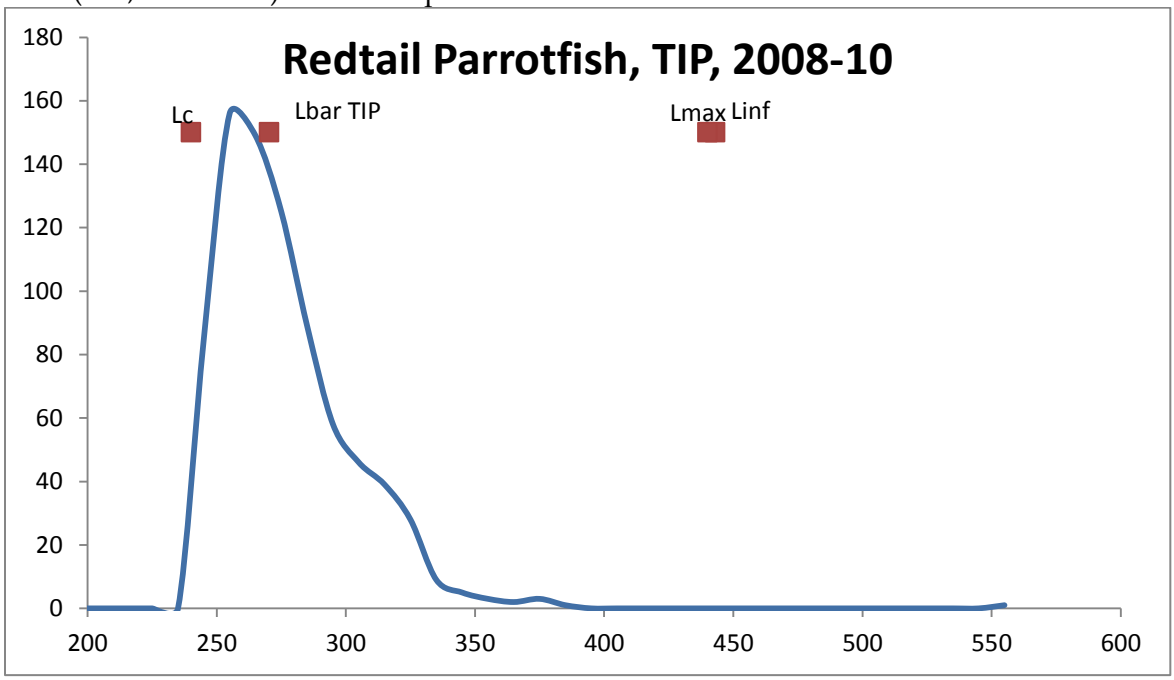


Figure 2.7: Length frequency data (TIP, 2008-2010), bounding Lc-Lmax range, and calculated Lbar (TIP & MRFSS, 2008-2010) for redtail parrotfish.

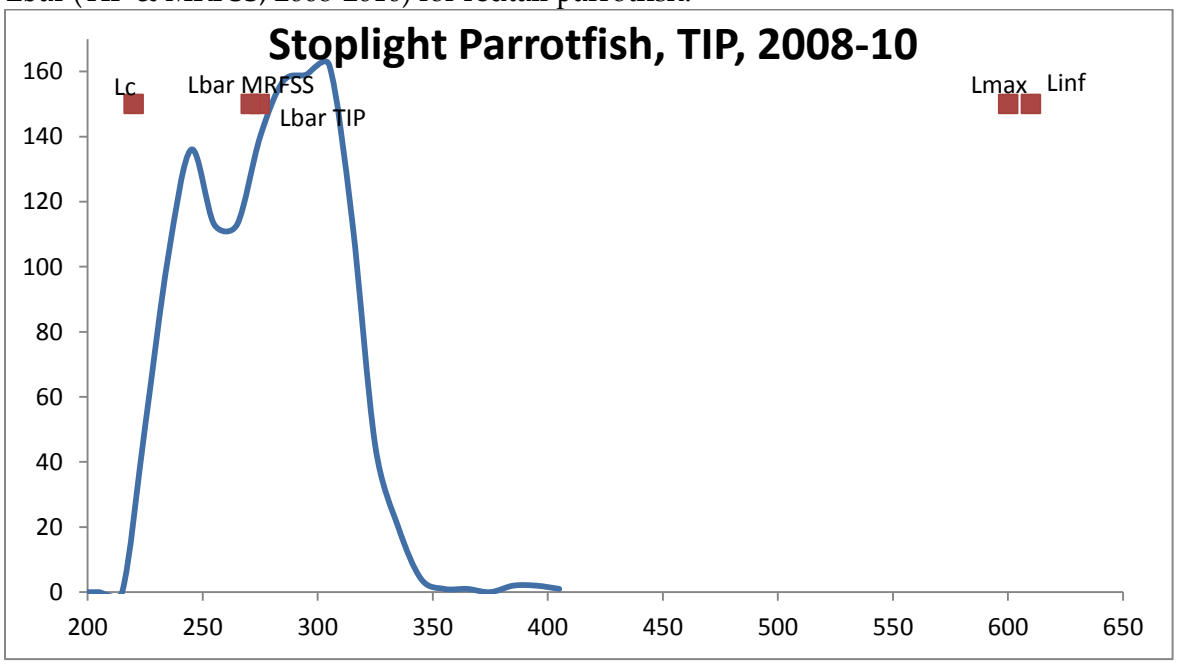
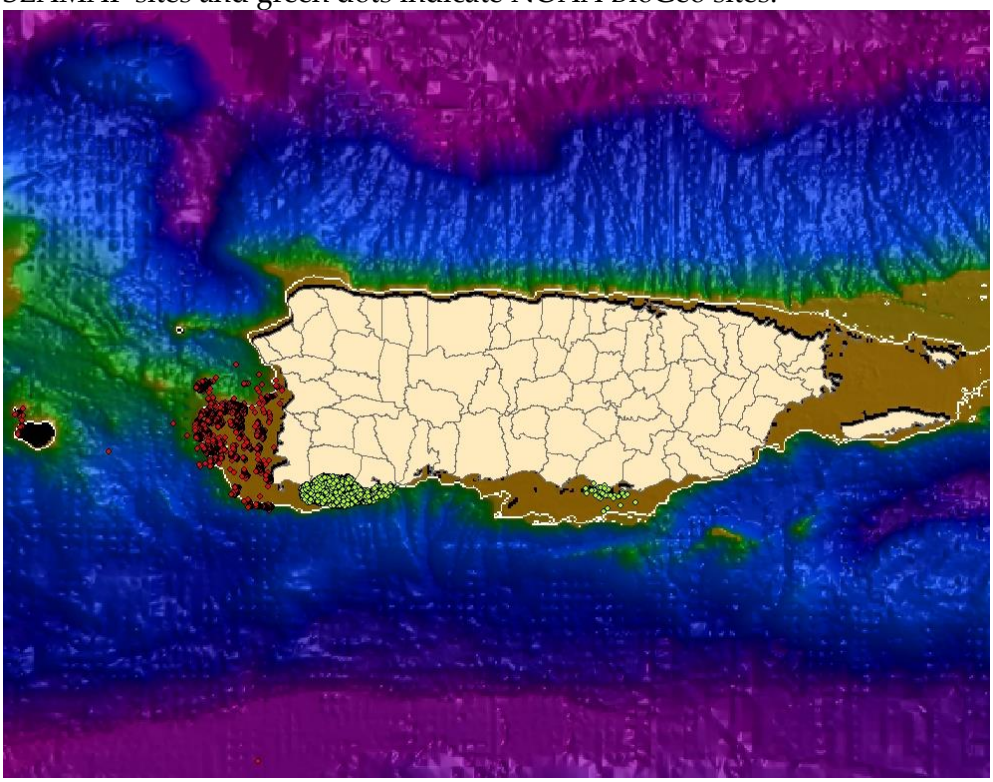


Figure 2.8: Map of Puerto Rico showing fishery-independent sampling sites. Red dots indicate SEAMAP sites and green dots indicate NOAA BioGeo sites.



3.0 THEORY OF LENGTH-BASED STOCK ASSESSMENT

Indicators are needed to assess reef fisheries and to support the implementation of an ecosystem approach to fisheries (Jennings 2005; Cury & Christensen 2005). The principal stock assessment indicator variable we used to quantify population status for the community of Puerto Rican reef fishes was average length ($\overline{L}$) of the exploited part of the population, which is a metabolic-based indicator that is highly correlated with population size (Beverton & Holt 1957; Ricker 1963; Pauly & Morgan 1987; Ehrhardt & Ault 1992; Kerr & Dickie 2001; Jennings *et al.* 2007). For exploited species, $\overline{L}$ directly reflects the rate of fishing mortality through alterations of the population size structure (Beverton & Holt 1957; Quinn & Deriso 1999). Theoretically, $\overline{L}$ at time *t* is expressed as

$$\overline{L}(t) = \frac{F(t)\int_{a_c}^{a_\lambda} N(a,t)\, L(a,t)\, da}{F(t)\int_{a_c}^{a_\lambda} N(a,t)\, da}\ , \qquad [1]$$

where a_c is the minimum age at first capture, a_λ the oldest age in the stock, *N(a, t)* the abundance for age class *a*, *L(a, t)* the length at age *a* and *F(t)* is the instantaneous fishing mortality rate at time *t*. In practice, $\overline{L}$ is usually estimated from lengths in the range of length at first capture L_c (or recruitment to the exploited phase of the stock) to the maximum observed length L_λ, the length of a fish at a_λ. *F(t)* could also be the viewing power of divers in fishery-independent visual surveys of reef fish populations (Ault *et al.* 1998).

Using estimates of $\overline{L}$ in time *t*, total instantaneous mortality rate $\hat{Z}(t)$ are estimated using the method of Ehrhardt and Ault (1992)

$$\left[\frac{L_\infty - L_\lambda}{L_\infty - L_c}\right]^{\frac{\hat{Z}(t)}{K}} = \frac{\hat{Z}(t)\left(L_c - \overline{L}(t)\right) + K\left(L_\infty - \overline{L}(t)\right)}{\hat{Z}(t)\left(L_\lambda - \overline{L}(t)\right) + \left(L_\infty - \overline{L}(t)\right)}\ , \qquad [2]$$

where K and L_∞ are parameters of the von Bertalanffy growth equation. Estimates of Z are computed using an iterative numerical algorithm (computer program LBAR; Ault *et al.* 1996; FAO [Food and Agriculture Organization of the United Nations] 2003). An illustrative graph of the relationship between average size in the exploited phase (Lbar) and fishing mortality rate (F) is shown in **Fig. 3.1**.

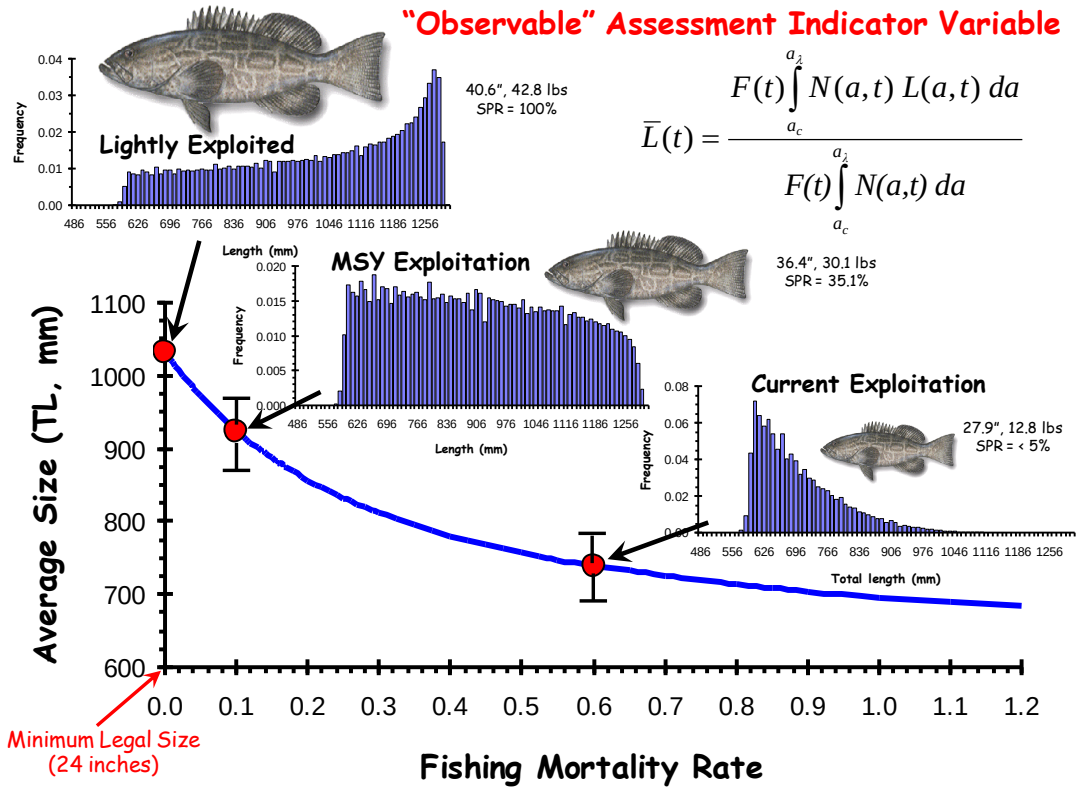


Figure 3.1.- Expected progression of average size in the exploited phase dependent of instantaneous fishing mortality rate.

4.0 POPULATION-DYNAMICS DATA & SOURCES

Life history parameters for maximum age, growth and maturity for the reef fish species considered (**Table 4.1**) were obtained from the literature syntheses of Ault *et al.* (1998, 2005*b*) and Claro *et al.* (2001).

Table 4.1: Life-history trait input parameters from literature syntheses of Ault *et al.* (1998, 2005*b*) and Claro *et al.* (2001), and resulting population mortality and sustainability benchmarks estimated from numerical models for exploited Puerto Rican reef fishes.

Complex	species	common	a_λ	K	L_{inf}	a_0	W_{inf}	L_m	t_m	L_C	t_c	L_{max}	α	β	M	M/K	SPRmsy
Groupers	*Cephalopholis fulvus*	**Coney**	17	0.145	698.9	-1.080	1.489	185	13	220	18	648.1	7.29E-05	2.570	0.176	1.215	36.16
Groupers	*Epinephelus cruentatus*	**Graysby**	15	0.130	415.0	-0.940	1.136	165		200	49	362.7	1.22E-05	3.044	0.200	1.536	47.42
Groupers	*Epinephelus guttatus*	**Red Hind**	17	0.200	471.4	-2.397	1.752	329	44	260	19	461.7	1.80E-04	2.614	0.176	0.881	34.16
Snappers	*Lutjanus buccanella*	**Blackfin**	9	0.084	729.7	-2.896	2.755	260	29	220	17	460.1	4.07E-05	2.735	0.333	3.977	32.08
Snappers	*Lutjanus cyanopterus*	**Cubera**	25	0.160	1200.0	-0.300	34.928		28	240	13	1179.1	1.32E-05	3.060	0.120	0.749	20.94
Snappers	Lutjanus jocu	**Dog**	20	0.100	854.0	-2.000	10.181	229	14	250	18	759.4	4.28E-05	2.857	0.150	1.498	33.30
Snappers	Lutjanus griseus	**Gray**	28	0.136	722.3	-0.863	5.248	230	24	240	25	708.0	3.05E-08	2.881	0.107	0.787	35.21
Snappers	Lachnolaimus maximus	**Hogfish**	23	0.080	912.6	-1.776	14.101	249		240	25	786.2	3.44E-05	2.910	0.130	1.632	31.51
Snappers	Lutjanus synagris	**Lane**	19	0.097	618.3	-1.728	3.245	206	30	210	31	534.8	4.52E-05	2.815	0.158	1.632	36.26
Snappers	Lutjanus mahogani	**Mahogony**	10	0.097	618.3	-1.728	3.177	130		250	43	420.1	8.18E-05	2.719	0.300	3.088	61.92
Snappers	Lutjanus analis	**Mutton**	29	0.129	938.7	-0.738	14.023	276	24	240	19	918.5	1.57E-05	3.011	0.103	0.801	31.91
Snappers	Lutjanus apodus	**Schoolmaster**	12	0.180	570.0	0.000	4.061	246	20	220	33	504.3	8.16E-04	2.430	0.250	1.387	38.90
Snappers	*Lutjanus vivanus*	**Silk**	9	0.092	781.1	-2.309	4.100	304	37	220	15	505.1	3.70E-05	2.781	0.333	3.618	26.25
Snappers	Rhomboplites aurorubens	**Vermilion**	14	0.144	650.0	-0.238	3.398	273		200	28	566.3	9.55E-09	3.040	0.214	1.486	31.02
Snappers	*Ocyurus chrysurus*	**Yellowtail**	14	0.170	483.8	-1.870	1.535	199	16	240	26	451.2	7.75E-05	2.718	0.214	1.259	45.58
Grunts	*Haemulon sciurus*	**Bluestriped**	8	0.300	413.0	0.000	1.496	205		200	26	375.5	2.00E-05	3.010	0.374	1.248	42.12
Grunts	*Haemulon flavolineatum*	**French**	12	0.179	294.0	0.000	0.565	177		190	70	259.7	9.06E-06	3.158	0.250	1.395	58.96
Grunts	*Haemulon album*	**Margate**	20	0.174	752.6	-0.450	8.575	428	53	210	17	731.2	1.52E-05	3.042	0.150	0.861	28.07
Grunts	*Anisotremus virginicus*	**Porkfish**	7	0.440	397.0	-0.350	1.721	231		210	16	381.4	1.01E-05	3.167	0.428	0.973	39.05
Grunts	*Haemulon plumieri*	**White**	18	0.186	511.9	-0.776	3.062	180		200	23	496.2	8.35E-06	3.161	0.166	0.895	36.14
Other Reef Fishes	*Caranx ruber*	**Bar Jack**	20	0.240	520.0	0.000	2.649	240	31	250	33	515.7	4.28E-06	3.237	0.150	0.624	39.76
Other Reef Fishes	*Caranx crysos*	**Blue Runner**	11	0.260	724.0	-0.480	5.282	391	30	220	11	687.4	1.07E-04	2.690	0.272	1.047	28.89
Other Reef Fishes	*Caranx hippos*	**Crevalle Jack**	18	0.160	1271.0	-0.690	29.368	648	45	190	4	1207.1	9.55E-05	2.734	0.166	1.040	24.15
Other Reef Fishes	*Acanthurus chirurgus*	**Doctorfish**	11	0.254	332.0	-0.630	0.960	194	32	180	29	314.7	1.19E-06	3.533	0.272	1.072	39.31
Other Reef Fishes	*Sphyraena barracuda*	**Great Barracuda**	32	0.090	1780.0	-1.190	42.946	877	77	350	15	1690.2	4.11E-06	3.083	0.094	1.040	25.32
Other Reef Fishes	*Caranx latus*	**Horse-eye Jack**	12	0.240	826.0	-0.510	20.118	440	31	320	18	785.0	4.76E-06	3.300	0.250	1.040	31.68
Other Reef Fishes	*Calamus bajonado*	**Jolthead Porgy**	13	0.220	704.0	-0.580	7.035	381	36	180	9	668.5	6.67E-05	2.818	0.230	1.047	26.49
Other Reef Fishes	*Balistes vetula*	**Queen Triggerfish**	13	0.230	759.0	-0.570	11.194	408	33	230	12	725.5	2.73E-05	2.990	0.230	1.002	28.36
Parrotfish	*Scarus taeniopterus*	**Princess**	6	0.480	366.0	-0.310	0.575	212	18	240	23	348.3	6.55E-05	2.709	0.499	1.040	55.63
Parrotfish	*Scarus vetula*	**Queen**	5	0.600	551.0	-0.230	2.258	306	13	250	9	527.1	1.35E-05	3.000	0.599	0.999	35.19
Parrotfish	*Sparisoma chrysopterum*	**Redtail**	8	0.624	443.0	0.000	1.466	251		240	15	440.0	1.07E-05	3.100	0.374	0.600	41.65
Parrotfish	*Sparisoma viride*	**Stoplight**	12	0.345	610.0	0.000	3.844	337		220	16	600.2	3.80E-05	2.900	0.250	0.725	33.45
Pelagics	*Scomberomorus regalis*	**Cero**	17	0.170	1864.0	-0.580	45.986	914	41	380	9	1770.1	3.20E-05	2.800	0.176	1.037	26.41
Pelagics	*Scomberomorus cavalla*	**King Mackerel**	19.3	0.150	1370.0	-0.750	18.706	693	47	450	23	1302.3	8.83E-06	2.973	0.155	1.035	30.56

Example growth and survivorship functions are shown in **Fig. 4.1**. Age-specific functions of length, weight, biomass, and fecundity are shown for red hind in **Fig. 4.2**. Relationships between the spawning potential ratio and the fishing mortality rate at maximum sustainable yield are plotted for a variety of reef-fish species in **Fig. 4.3**. Relationships between maximum size and natural mortality rate and growth rate are shown in **Fig. 4.4**.

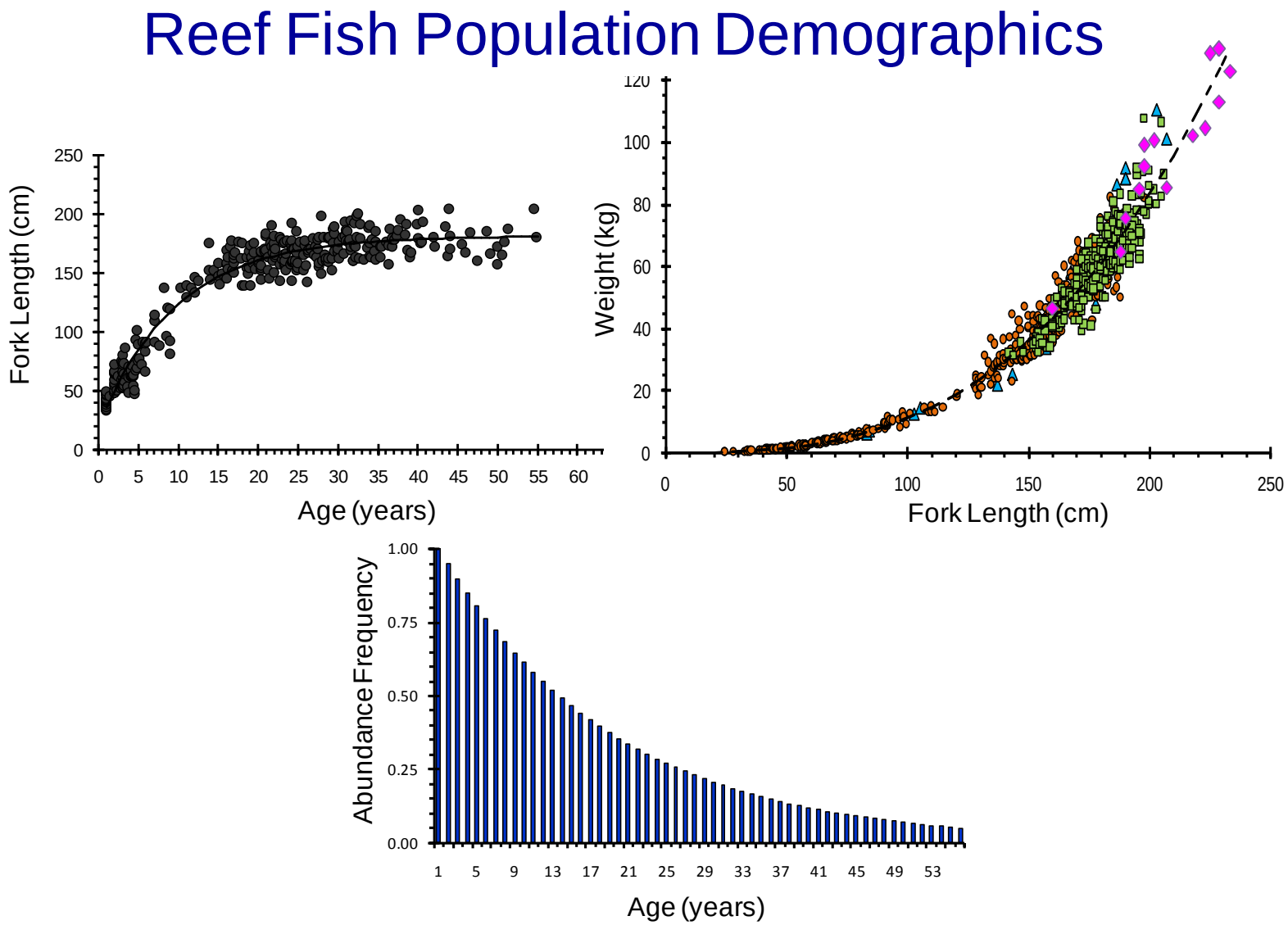


Figure 4.1: Growth and mortality dependent on age population demographic relationships for a typical Puerto Rico reef fish.

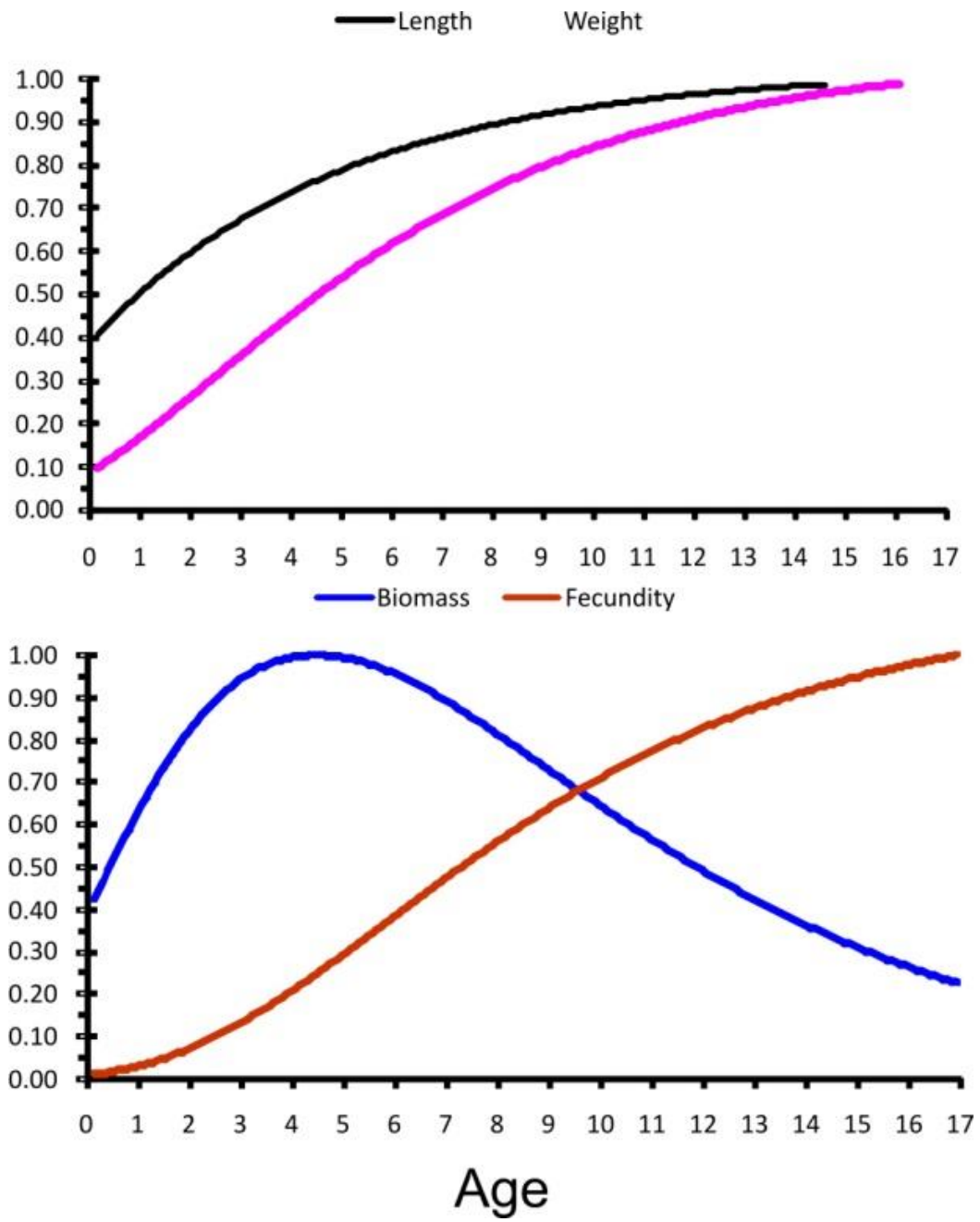


Figure 4.2: Inter-relationships of growth and mortality dependent on age in the context of population biomass and fecundity (reproductive potential) for red hind, a typical Puerto Rico reef fish.

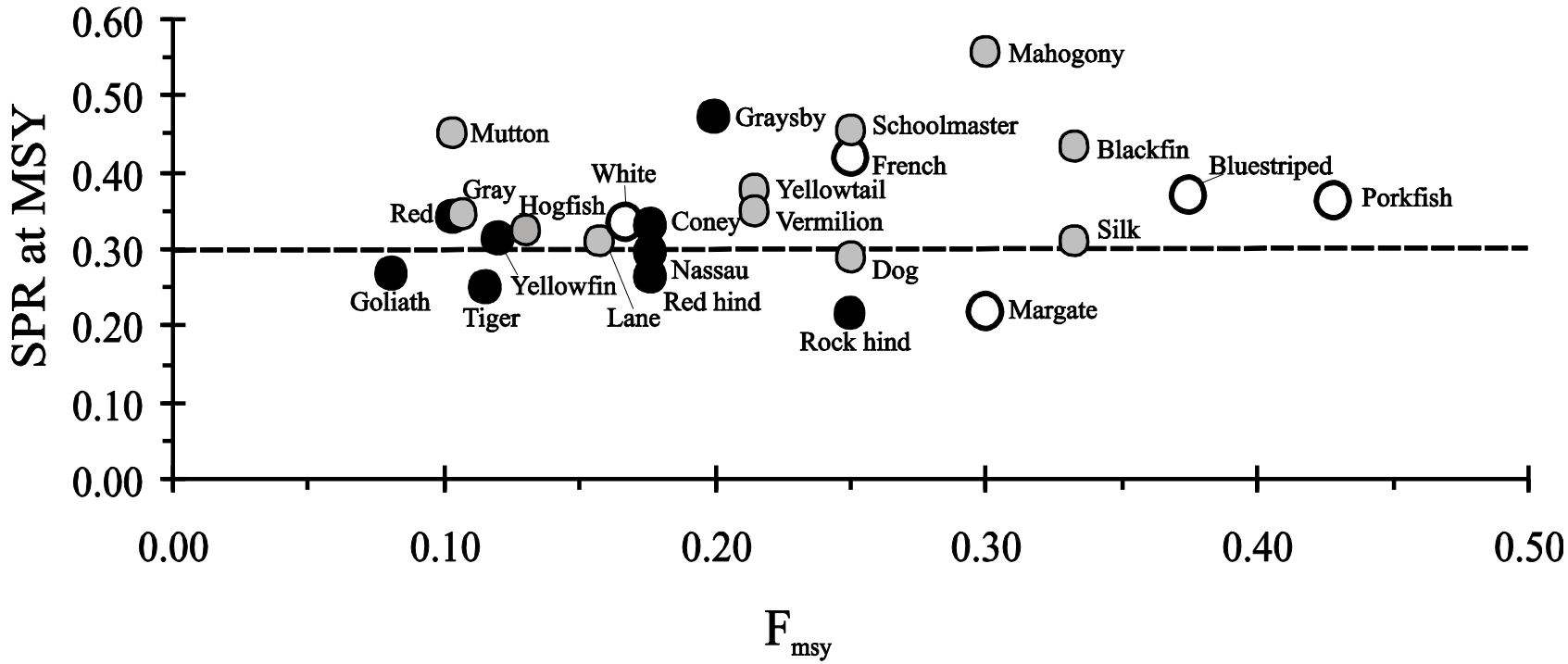


Figure 4.3: Estimated spawning potential ratio (SPR) at maximum sustainable yield (MSY) dependent on F_{msy} for 25 exploited species (groupers = dark circles, snappers = shaded circles and grunts = open circles) from Puerto Rico. The horizontal dashed line is the 30% SPR USA federal standard for sustainability.

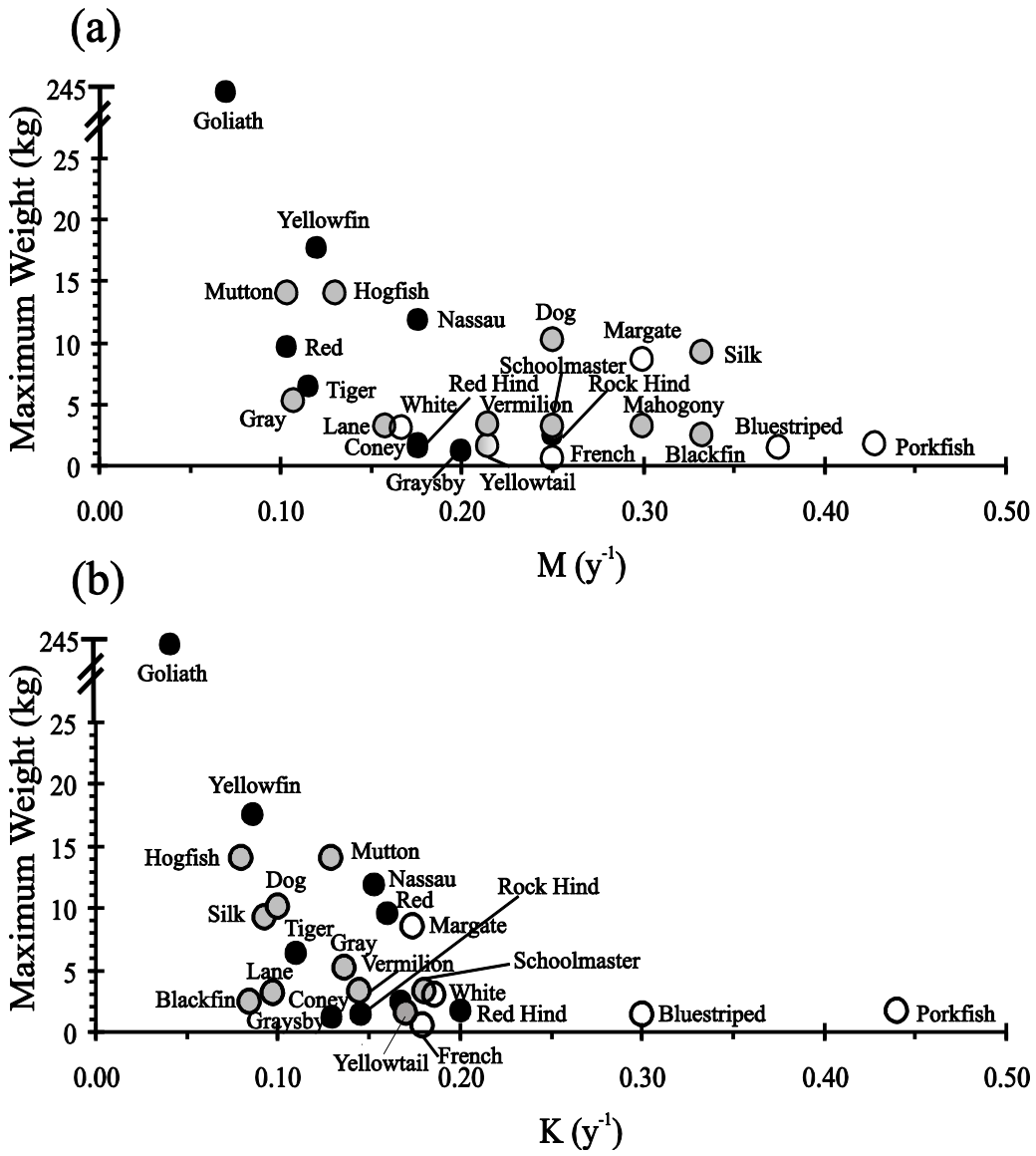


Figure 4.4: Relationships between maximum size (weight in kg) and (*a*) natural mortality rate *M* (y^{-1}), and (*b*) Brody growth coefficient *K* (y^{-1}) for 25 species (groupers = dark circles, snappers = shaded circles and grunts = open circles) of Puerto Rican coral reef fish.

5.0 NUMERICAL POPULATION MODELING

We used a stochastic length-based numerical population model (Ault & Olson 1996; Ault *et al.* 1998) to calculate ensemble numbers at given lengths $\tilde{N}_\gamma$ over time for a given cohort γ, generalized as

$$\tilde{N}_\gamma(L_\gamma, t) = \int_{a_r}^{a_\lambda} R_\gamma(\tilde{\tau - a}) S(a)\theta(a)P(L \mid a)da \ , \qquad [3]$$

where $R_\gamma(\tau - a)$ is cohort recruitment lagged back to birth date, *S(a)* is survivorship to age *a*, *θ (a)* is a logistic model of sex ratio at age to account for hermaphroditic life histories common to tropical reef fishes, and *P(L|a)* is the probability of being length *L* given the fish is age *a*. This population model simulates the time-transition of recruits to mature adults to maximum size-age using a number of dynamic functions to regulate population birth, growth, and survivorship processes, including fishery harvests (details in Ault *et al*. 1998). A conceptual flowchart of the REEFS model is shown in **Fig. 5.1**.

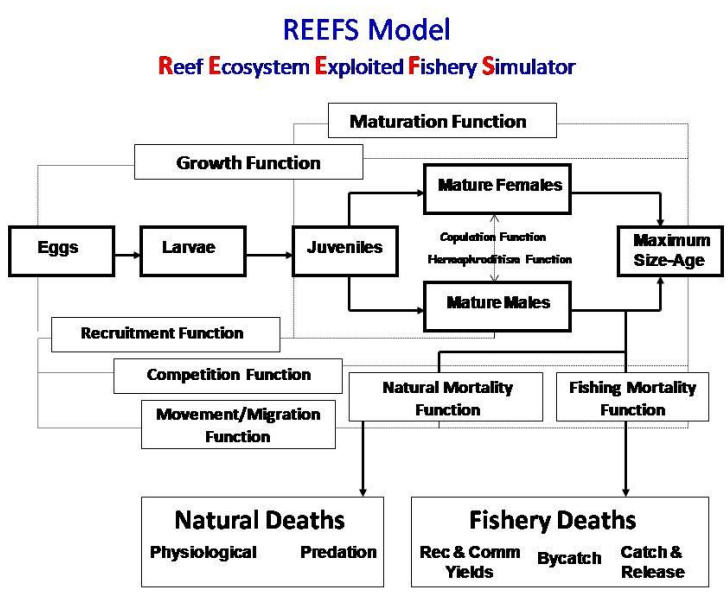


Figure 5.1: Flowchart of the REEFS (Reef Ecosystem Exploited Fishery Simulation) model.

We calibrated the numerical model (Eq. 3) through a consistency check between model estimates of $\bar{L}$, using $\hat{Z}$ from Eq. (2) as the input, and the $\hat{\bar{L}}$ estimated from data. Additionally, we evaluated the two major components of *Z*, namely fishing mortality rate *F* and natural mortality rate *M*. In this process, we estimated *M* from lifespan applying the procedure of Alagaraja (1984; *sensu* Hoenig 1983) assuming that 5% of a cohort survives to the maximum age/size, and *F* was estimated by subtracting *M* from *Z* (Ault *et al*. 1998). We used the calibrated model to compute management benchmarks of stock status to evaluate sustainability in the following analytical process.

6.0 SUSTAINABILITY BENCHMARKS AND RESOURCE RISK ANALYSES

6.1 Description

Sustainability analyses involved comparison of various population metrics at current levels of fishing mortality against standard fishery management sustainability benchmarks. We configured the simulation model to assess several reference points to address several sustainability risks, including fishery yields, spawning potential ratio (SPR; Clark 1991) and precautionary control rules (for example Restrepo & Powers 1999). Since population biomass *B(a,t)* is the product of numbers-at-age times weight-at-age *W(a,t)*, yield in weight Y_w from a species during an instant *t* was calculated as

$$Y_w(F, L_c, t) = F(t)\int_{L_c}^{L_\lambda} B(L \mid a,t)dL = F(t)\int_{L_c}^{L_\lambda} N(L \mid a,t)W(L \mid a,t)dL \quad . \qquad [4]$$

We obtained an important measure of stock reproductive potential, spawning stock biomass (SSB) at a given level of fishing mortality, by integrating over individuals in the population between the size of sexual maturity (L_m; 50% maturity, assumed knife-edged) and the maximum size (L_λ)

$$SSB(t) = \int_{L_m}^{L_\lambda} B(L \mid a,t)dL \quad . \qquad [5]$$

Maximum spawning biomass is obtained under conditions of no fishing mortality. Spawning potential ratio (SPR) is a management benchmark that measures a stock's potential to produce yields on a sustainable basis, and is computed as the ratio of current *SSB(t)* relative to that of an unexploited stock.

$$SPR = \frac{SSB_{\text{exploited}}}{SSB_{\text{unexploited}}} \quad . \qquad [6]$$

Estimated SPRs were compared to USA Federal standards which define 30% SPR as the threshold below which a stock is no longer sustainable at current exploitation levels (see Gabriel *et al.* 1989; Restrepo *et al*. 1998). Evaluation of control rules involved determination of F_{msy} (F generating maximum sustainable yield, MSY) and B_{msy} (population biomass at MSY) (**Fig. 6.1.1**). We defined F = M as a proxy for F_{msy} (Quinn & Deriso 1999; Restrepo & Powers 1999).

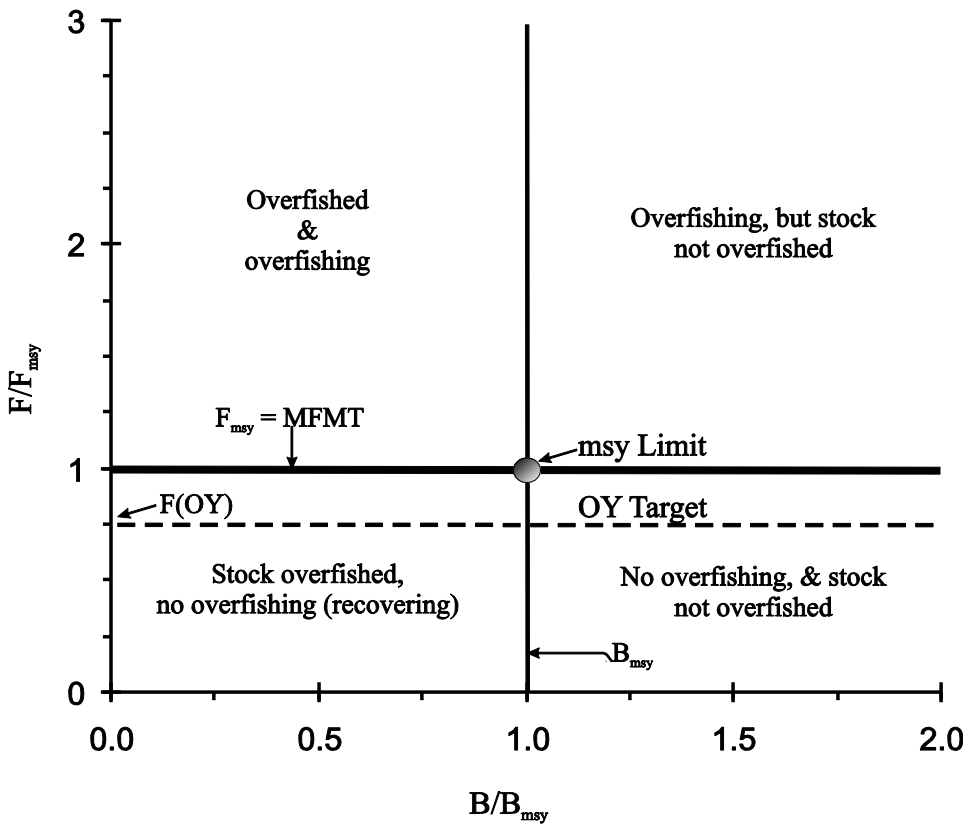


Figure 6.1.1: Conceptual diagram showing limit and target control rules. Target control rules specify desirable levels of fishing for sustainable stocks (for example F(OY) that produces optimal yield OY). Limit control rules define sustainability benchmarks or a cut-off above which there is an unacceptable risk of serious or irreversible harm to the resource and requires strong management intervention. If the maximum fishing mortality threshold (MFMT, equivalent to the F(MSY) limit in our analysis) is exceeded, then management actions in the form of reductions in F (or rebuilding plans) must be implemented to reverse the situation and move the stock to the lower right quadrant ($B/B_{msy} > 1$ and $F/F_{msy} < 1$). A more precautionary control rule, as suggested by Restrepo and Powers (1999), is to set the threshold MFMT 'safely below' the MSY limit (for example F(OY)= MFMT = 0.75 × F(MSY)).

6.2 Current population status.

Table 6.2.1: Current status exploitation statistics for all computable species (2008-2010).

									TIP						MRFSS		
Complex	**species**	**common**	a_λ	L_C	L_{max}	**SPRmsy**	**Lbar**	**F**	**F/F_{msy}**	**SPR**	**B/Bmsy**	**Lbar**	**F**	**F/F_{msy}**	**SPR**	**B/B_{msy}**
Groupers	*Cephalopholis fulvus*	**Coney**	17	220	648.0994251	36.16	255.41	1.6398	9.3054	3.7678	0.1353	275.87	0.9217	5.2308	6.4982	0.2082
Groupers	*Epinephelus cruentatus*	**Graysby**	15	200	362.7479816	47.42	262.18	0.0844	0.4226	69.7943	1.4114					
Groupers	*Epinephelus guttatus*	**Red Hind**	17	260	461.6593584	34.16	344.29	0.1176	0.6677	47.2274	1.2293	336.54	0.1718	0.9753	34.9608	1.0169
Snappers	*Lutjanus buccanella*	**Blackfin**	9	220	460.1002934	32.08	297.42	0.0750	0.2253	74.8574	1.7089	293.53	0.1129	0.3392	65.2803	1.5534
Snappers	*Lutjanus cyanopterus*	**Cubera**	25	240	1179.051295	20.94	617	0.1259	1.0507	19.460253	0.9517102					
Snappers	Lutjanus jocu	**Dog**	20	250	759.3741028	33.30	399.4	0.1504	1.0041	33.1727	0.9969	344.2	0.3912	2.6118	11.8395	0.38
Snappers	Lutjanus griseus	**Gray**	28	240	708.0455012	35.21	334.2	0.4532	4.2359	6.4124	0.2022					
Snappers	Lachnolaimus maximus	**Hogfish**	23	240	786.2093658	31.51	368.09	0.2078	1.5954	19.0643	0.6276					
Snappers	Lutjanus synagris	**Lane**	19	210	534.8184666	36.26	269.8	0.4052	2.5699	14.0758	0.4555	267.0	0.4375	2.7740	12.8944	0.43
Snappers	Lutjanus mahogani	**Mahogony**	10	250	420.0803	61.92	299.60	0.2712	0.9053	64.0299	1.0337					
Snappers	Lutjanus analis	**Mutton**	29	240	918.4863191	31.91	435.2	0.2293	2.2202	12.2408	0.3941	433.1	0.2343	2.2686	11.8650	0.3826
Snappers	Lutjanus apodus	**Schoolmaster**	12	220	504.264681	38.90	303.5	0.3152	1.2626	31.8902	0.8634					
Snappers	*Lutjanus vivanus*	**Silk**	9	220	505.1346864	26.25	332.66	<0	<0	133.4981	2.8719	337.15	<0	<0	152.2975	3.1865
Snappers	Rhomboplites aurorubens	**Vermilion**	14	200	566.3450699	31.02	253.99	0.8422	3.9355	3.6458	0.2502	235.06	1.4902	6.9637	0.8557	0.1519
Snappers	*Ocyurus chrysurus*	**Yellowtail**	14	240	451.2176217	45.58	324.2	0.0862	0.4030	69.3503	1.4710	314.3	0.1611	0.7530	53.3672	1.16
Grunts	*Haemulon sciurus*	**Bluestriped**	8	200	375.5334853	42.12	240.3	0.9062	2.4197	18.8479	0.5710					
Grunts	*Haemulon flavolineatum*	**French**	12	190	259.6850964	58.96	200.82	1.2912	5.1722	23.8900	0.6256					
Grunts	*Haemulon album*	**Margate**	20	210	731.1605244	28.07	316.63	0.5616	3.7493	2.5290	0.1954					
Grunts	*Anisotremus virginicus*	**Porkfish**	7	210	381.3583648	39.05	225.28	4.516783	10.5532	1.3460	0.2454					
Grunts	*Haemulon plumieri*	**White**	18	200	496.2452834	36.14	250.01	0.8077	4.8538	6.3127	0.2022					
Other Reef Fishes	*Caranx ruber*	**Bar Jack**	20	250	515.7205315	39.76	313.1	0.6373	4.2547	8.870196	0.2616	316.6	0.5832	3.8930	9.8751	0.2856
Other Reef Fishes	*Caranx crysos*	**Blue Runner**	11	220	687.4020806	28.89	357.63	0.4176	1.5334	16.7122	0.6731	295.49	1.2035	4.4199	1.7499	0.2079
Other Reef Fishes	*Caranx hippos*	**Crevalle Jack**	18	190	1207.110229	24.15						520.5000	0.1950	1.1721	19.5155	0.8405
Other Reef Fishes	*Acanthurus chirurgus*	**Doctorfish**	11	180	314.6929321	39.31	202.43	1.1949	4.3875	6.9569	0.3749					
Other Reef Fishes	*Sphyraena barracuda*	**Great Barracuda**	32	350	1690.228402	25.32						647.7300	0.2486	2.6565	4.6516	0.2671
Other Reef Fishes	*Caranx latus*	**Horse-eye Jack**	12	320	784.9744611	31.68	461.70	0.3642	1.4589	20.6548	0.7154					
Other Reef Fishes	*Calamus bajonado*	**Jolthead Porgy**	13	180	668.5125769	26.49	253.44	1.1193	4.8572	0.8913	0.1441					
Other Reef Fishes	*Balistes vetula*	**Queen Triggerfish**	13	230	725.5215557	28.36	309.13	1.0772	4.6745	1.4649	0.1672	337.53	0.6710	2.9123	5.0136	0.3027
Parrotfish	*Scarus taeniopterus*	**Princess**	6	240	348.2952435	55.63	255.00	3.0527	6.1139	21.3243	0.5443					
Parrotfish	*Scarus vetula*	**Queen**	5	250	527.103433	35.19	291.76	3.1256	5.2171	3.1339	0.2722					
Parrotfish	*Sparisoma chrysopterum*	**Redtail**	8	240	440.0007275	41.65	270.28	3.1871	8.5103	3.7678347	0.19318365					
Parrotfish	*Sparisoma viride*	**Stoplight**	12	220	600.2286078	33.45	274.90	1.8532	7.4245	0.8778026	0.11563633	271.00	2.0403	8.1742	0.6490576	0.11
Pelagics	*Scomberomorus regalis*	**Cero**	17	380	1770.132896	26.41	481.97	2.1278	12.0747	0.0130	0.0334	529.91	1.3367	7.5861	0.1699	0.0597
Pelagics	*Scomberomorus cavalla*	**King Mackerel**	19.3	450	1302.301365	30.56	775.23	0.1117	0.7196	41.1884	1.2834	798.00	0.0811	0.5222	51.6011	1.5593

Figure 6.2.1: Current status (2008-2010) for all assessable species in the (TIP) database.

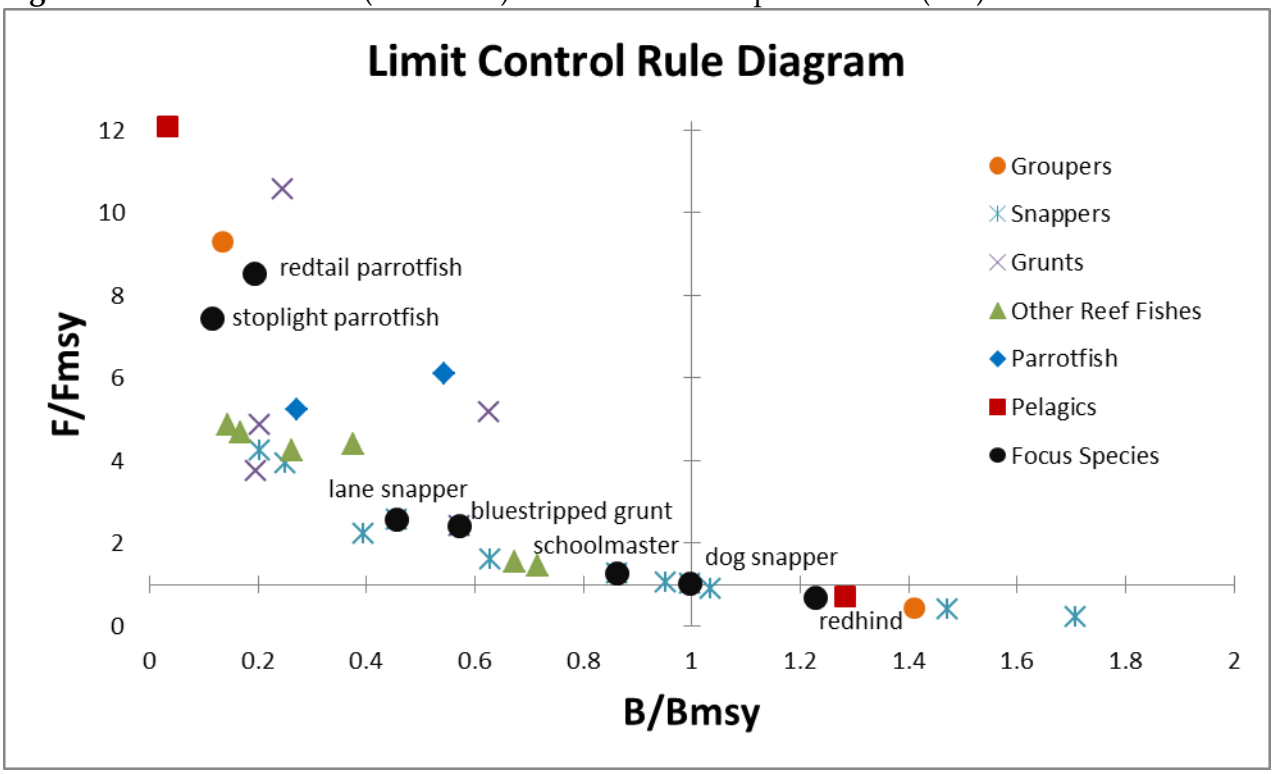


Fig. 6.2.2: SPR under equilibrium exploitation at F=Fmsy for all assessable species in the.

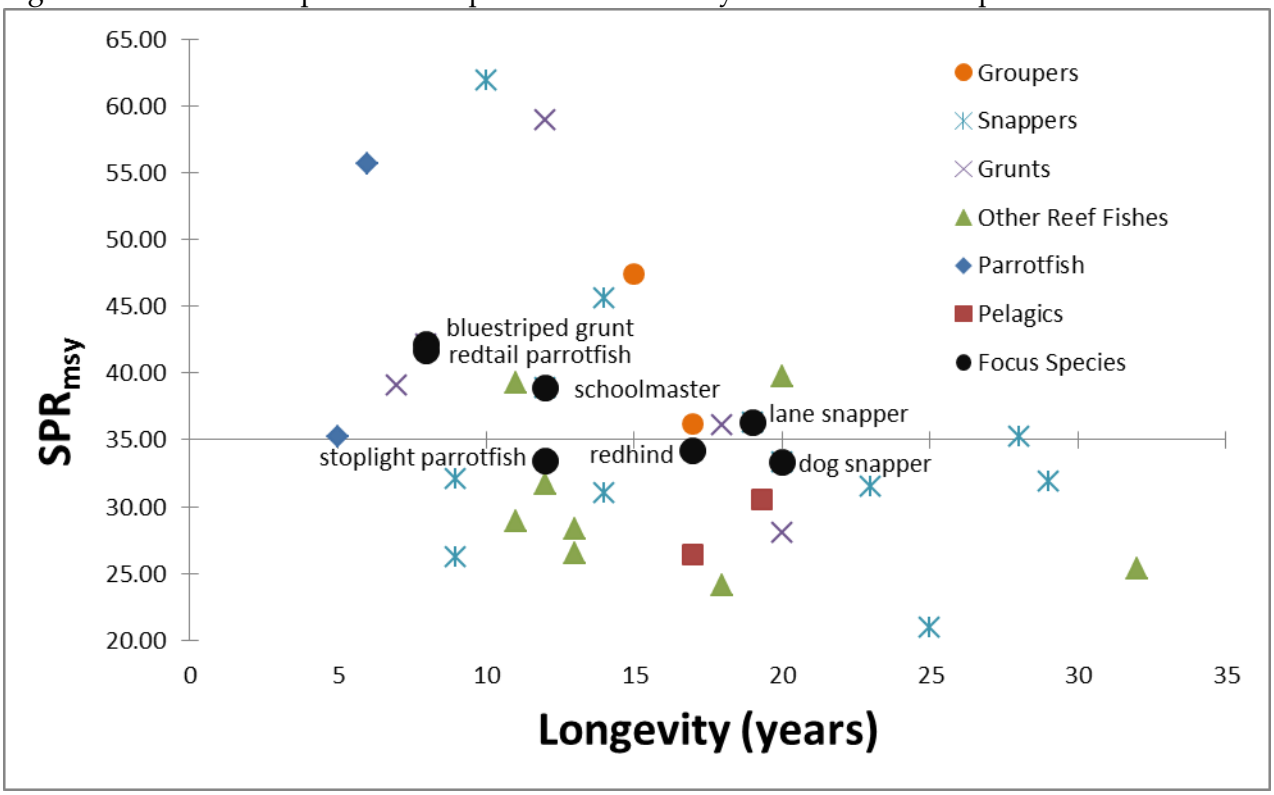
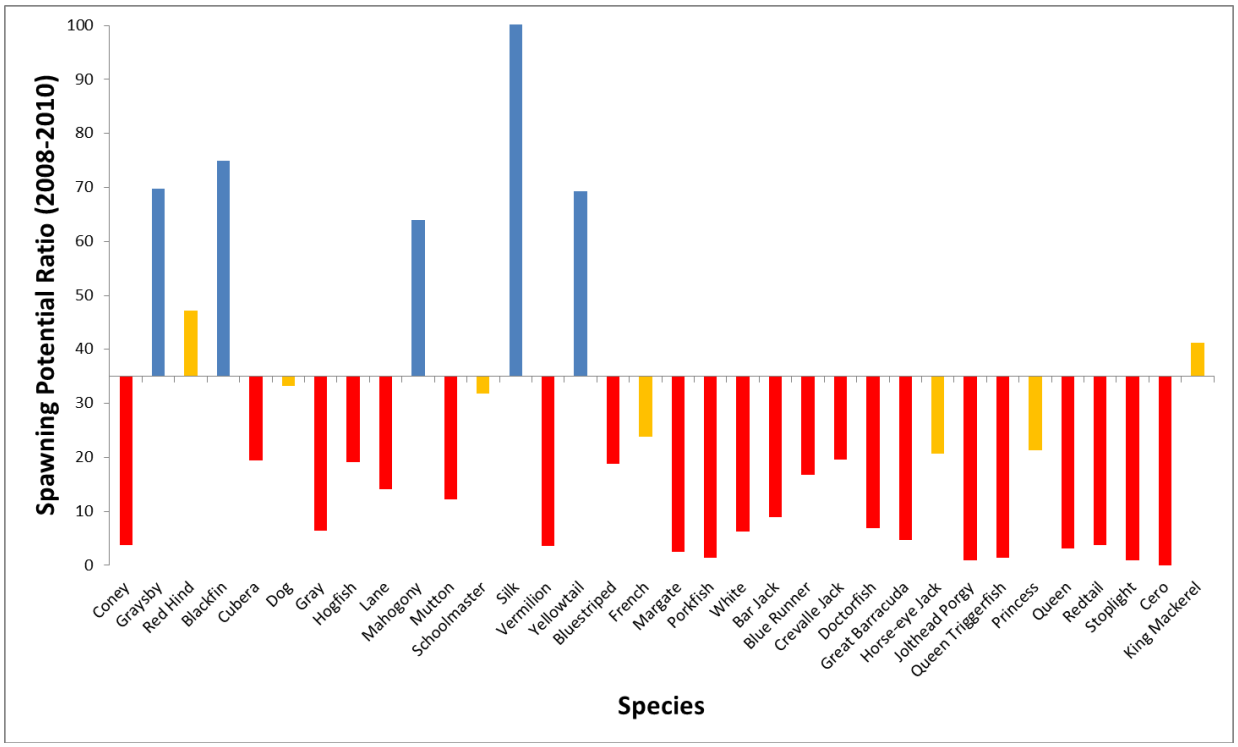


Figure 6.2.3: Current status (2008-2010) spawning potential ratio for all species with available data.



6.3 Historic Exploitation & Sustainability Benchmarks of Focus Species

A user-friendly software package, Mortality and Assessment and Stock Simulation Tool (MAST), was developed to facilitate training of DNER personnel in applying sustainability benchmark analyses to Puerto Rico reef-fishes (**Appendix A**). Following are MAST output graphics from length-based sustainability analyses applied to seven focus species: red hind, dog snapper, schoolmaster, bluestriped grunt, lane snapper, redtail parrotfish, and stoplight parrotfish.

6.3.1 Red hind

Figure 6.3.1.1: Yield per recruit in numbers under all conditions of equilibrium F and Lc.

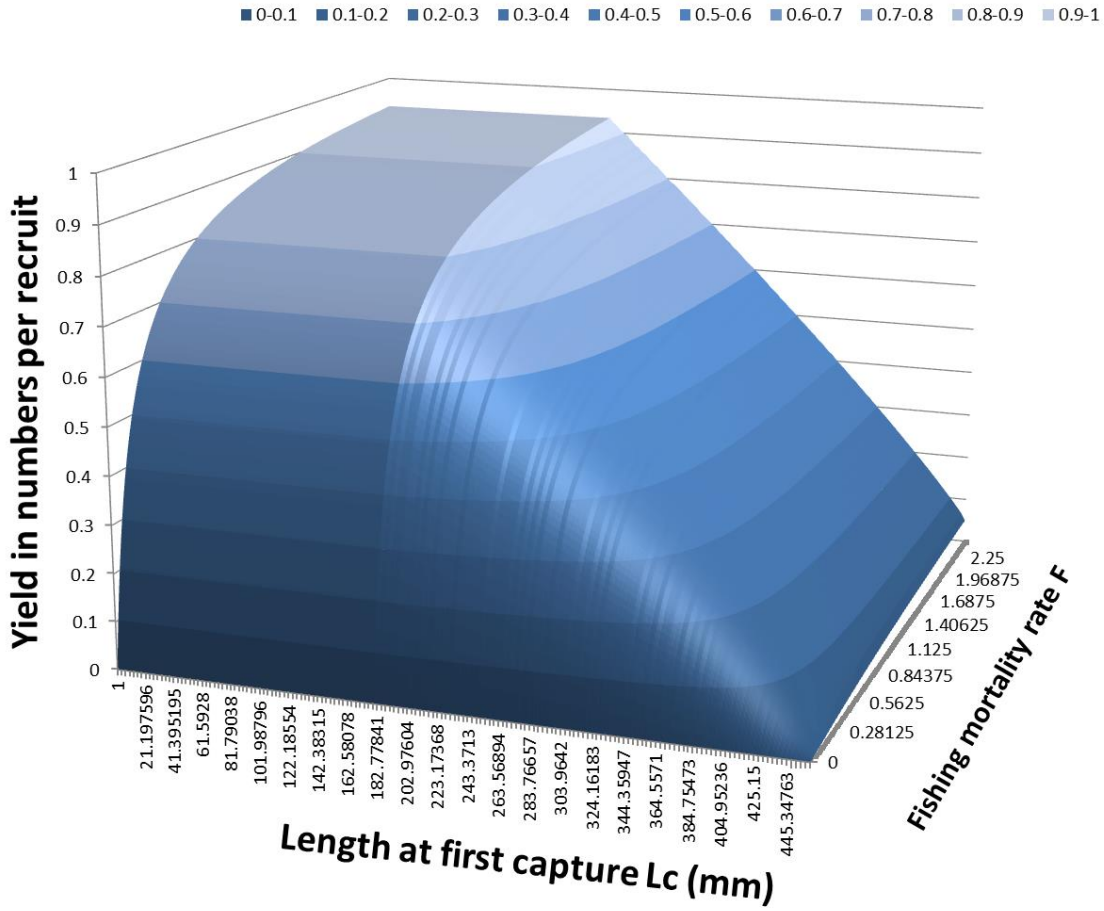


Figure 6.3.1.2: Yield per recruit in weight under all conditions of equilibrium F and Lc.

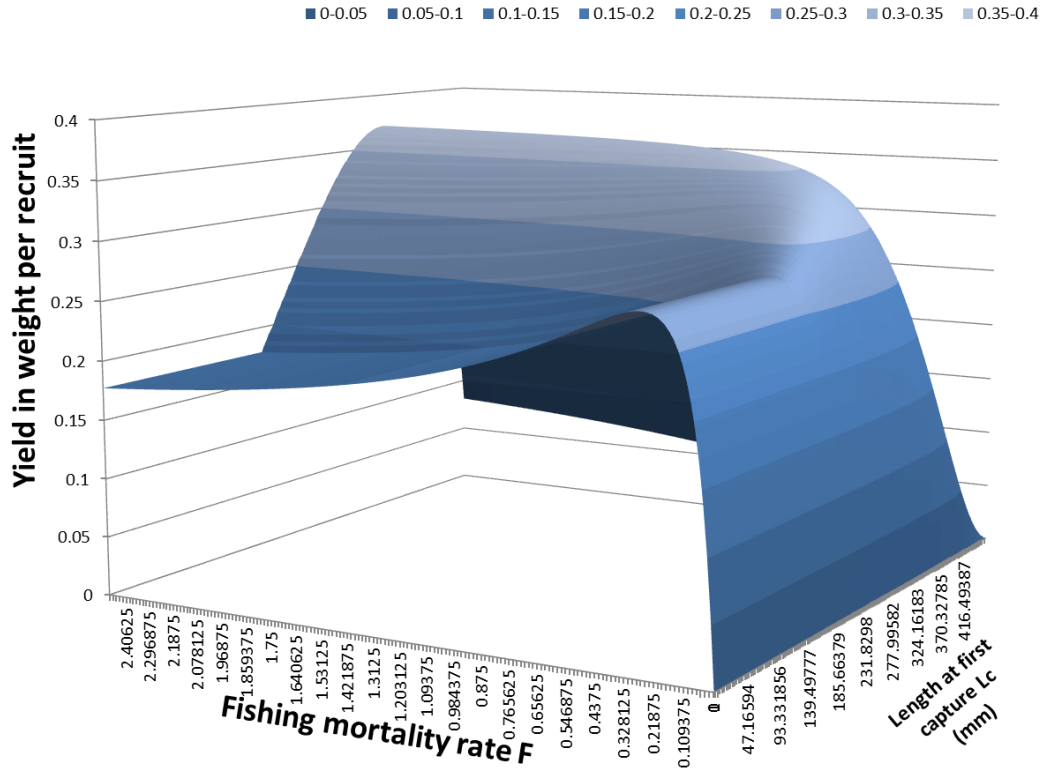


Figure 6.3.1.3: Eumetric line. Calculates the length at first capture that obtains the maximum yield for every potential value of F.

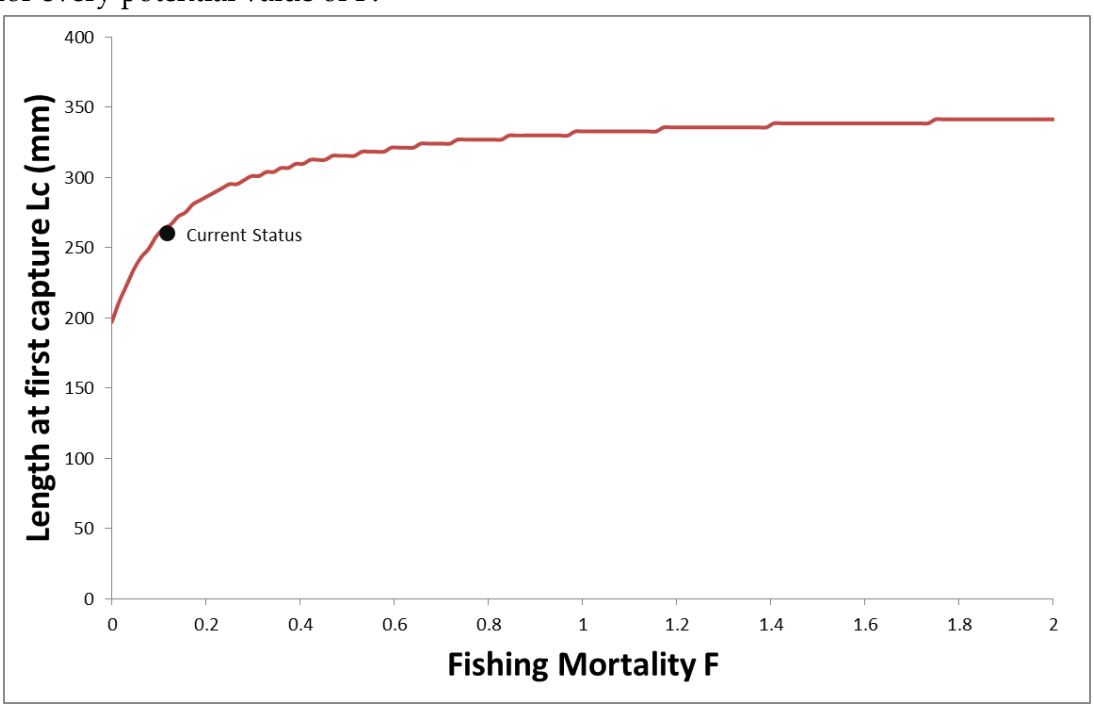


Figure 6.3.1.4: Spawning potential ratio under all conditions of equilibrium F and Lc.

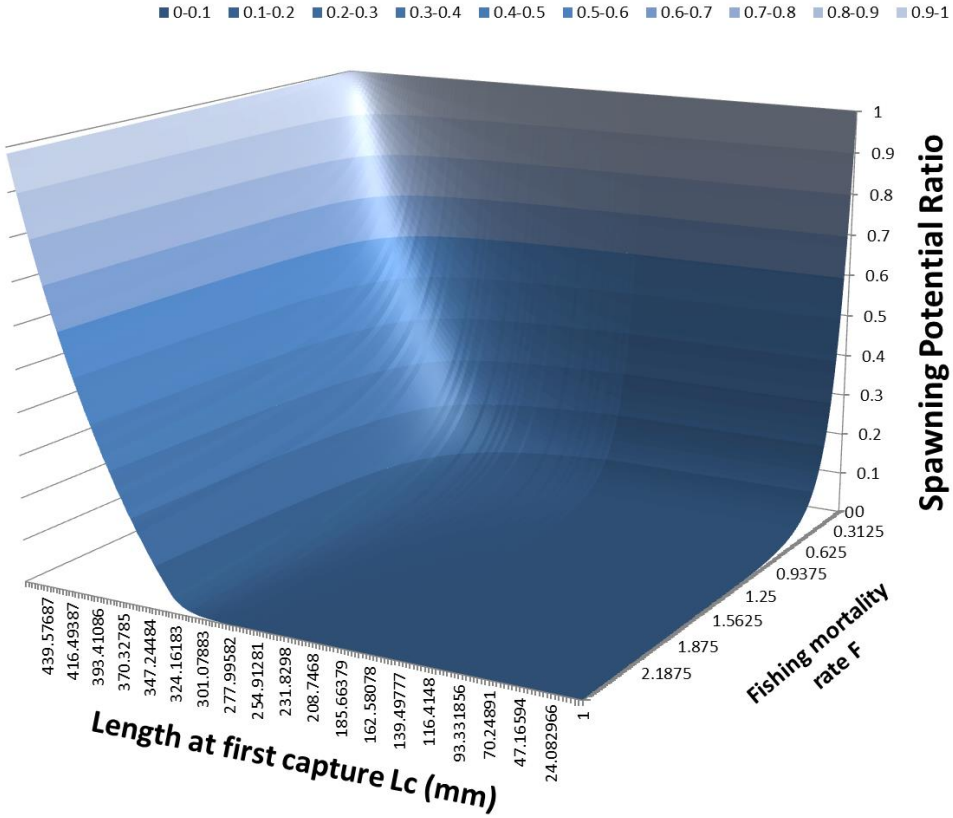
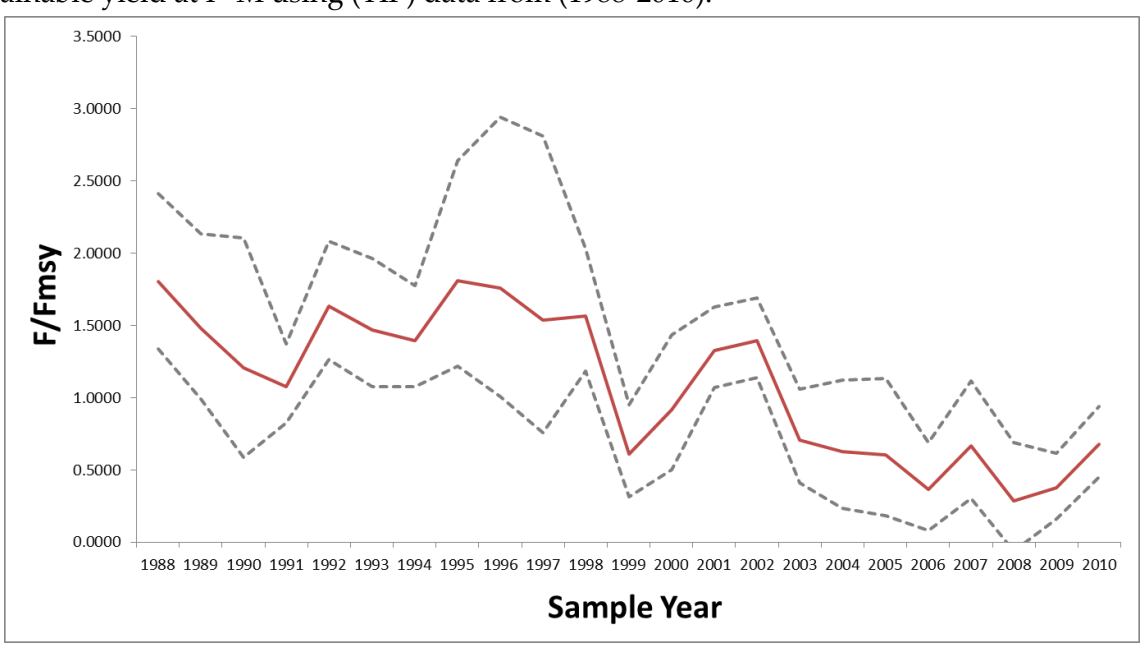


Figure 6.3.1.5: Annual exploitation rate with 95% confidence bounds relative to optimum sustainable yield at F=M using (TIP) data from (1988-2010).



6.3.2 Dog snapper

Figure 6.3.2.1: Yield per recruit in numbers under all conditions of equilibrium F and Lc.

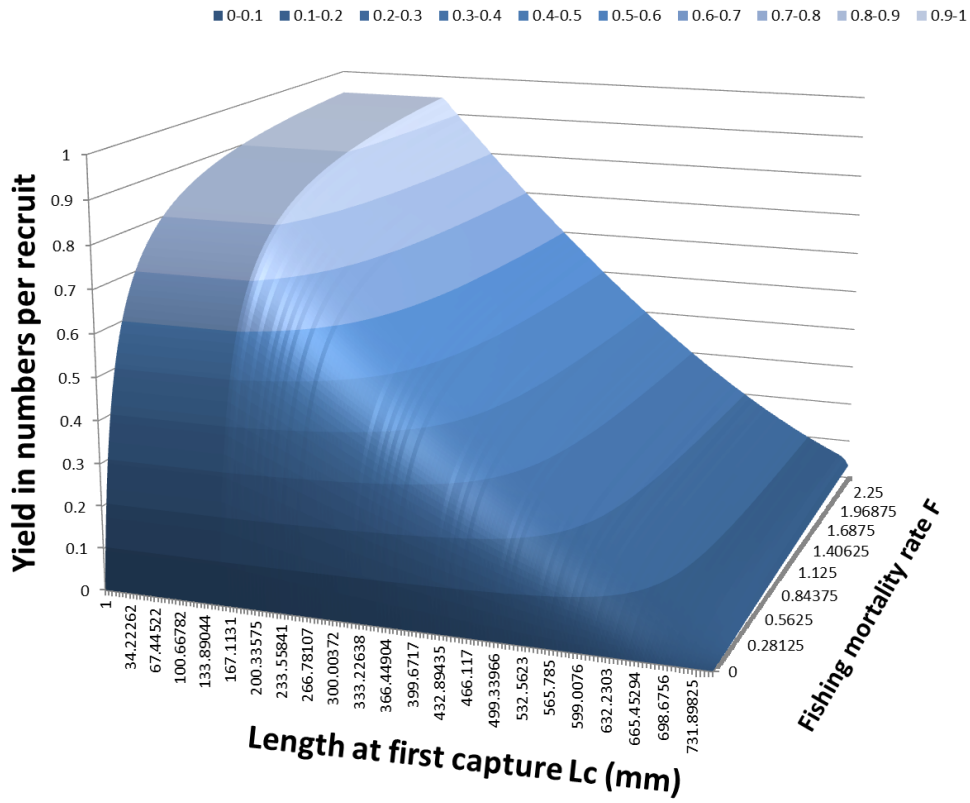


Figure 6.3.2.2: Yield per recruit in weight under all conditions of equilibrium F and Lc.

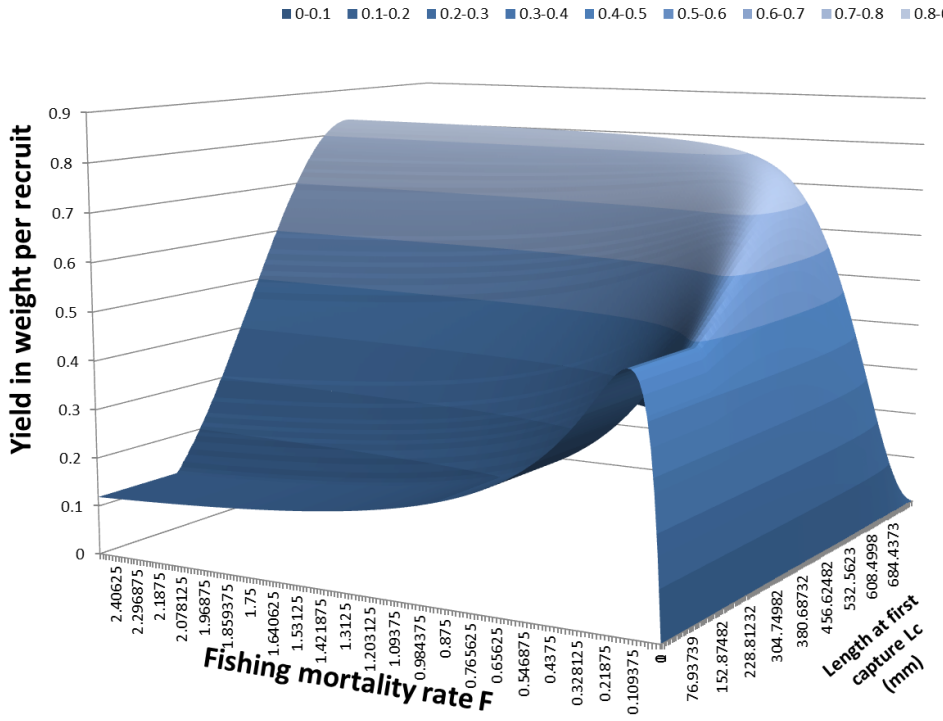


Figure 6.3.2.3: Eumetric line. Calculates the length at first capture that obtains the maximum yield for every potential value of F.

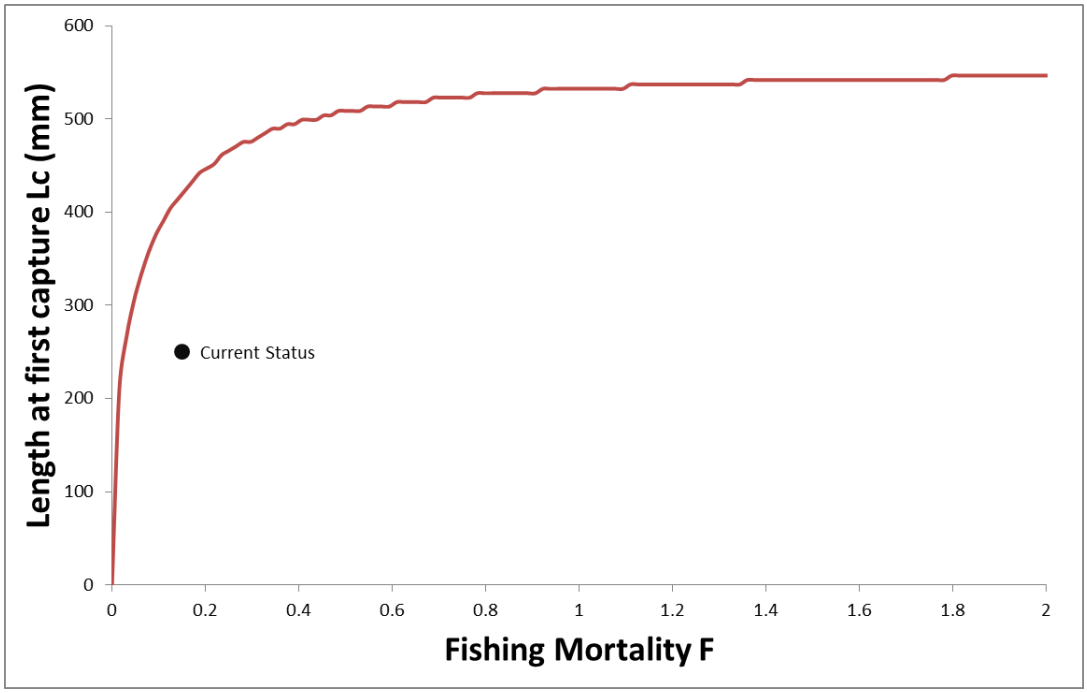


Figure 6.3.2.4: Spawning potential ratio under all conditions of equilibrium F and Lc.

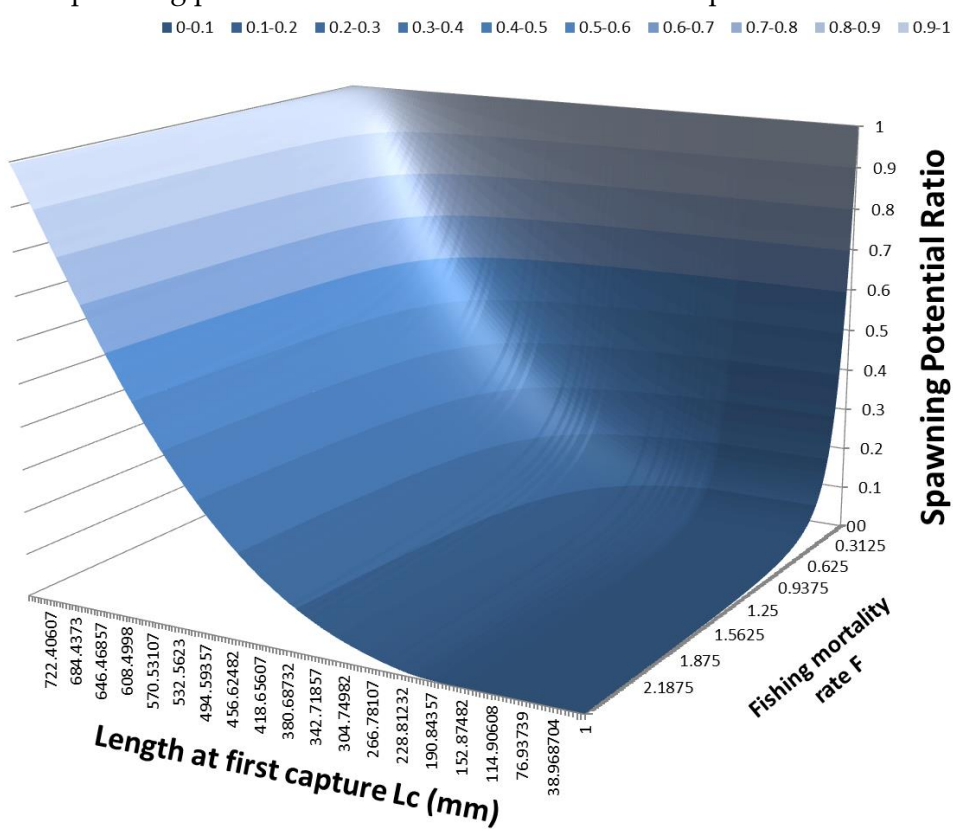
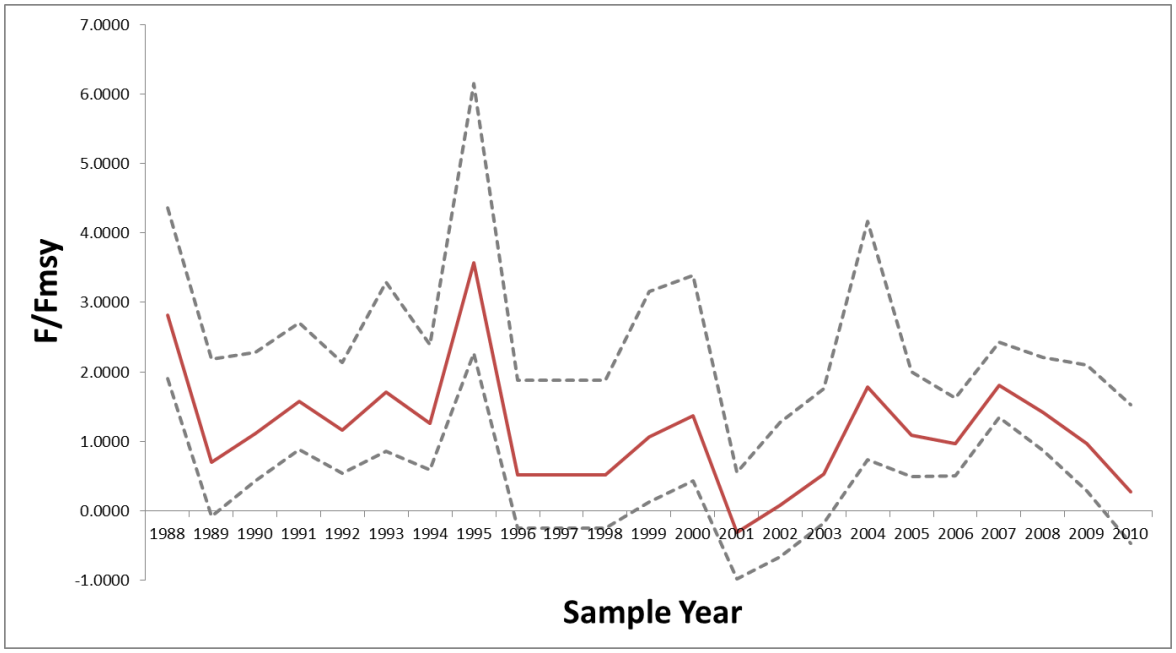


Figure 6.3.2.5: Annual exploitation rate with 95% confidence bounds relative to optimum sustainable yield at F=M using (TIP) data from (1988-2010).



6.3.3 Schoolmaster

Figure 6.3.3.1: Yield per recruit in numbers under all conditions of equilibrium F and Lc.

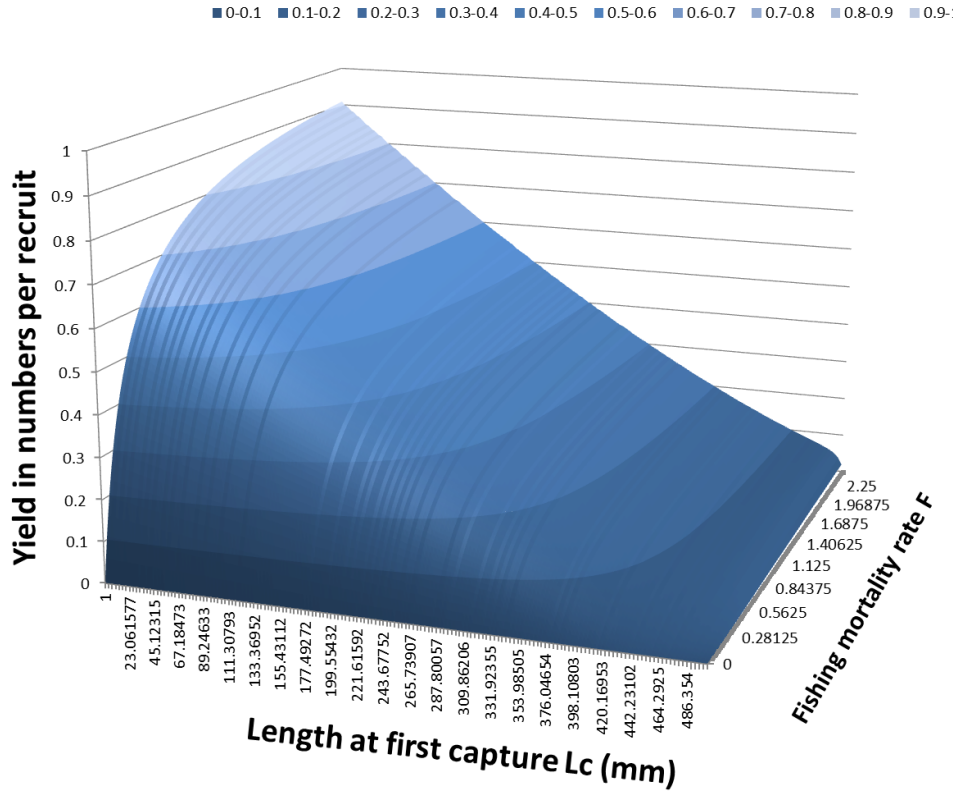


Figure 6.3.3.2: Yield per recruit in weight under all conditions of equilibrium F and Lc.

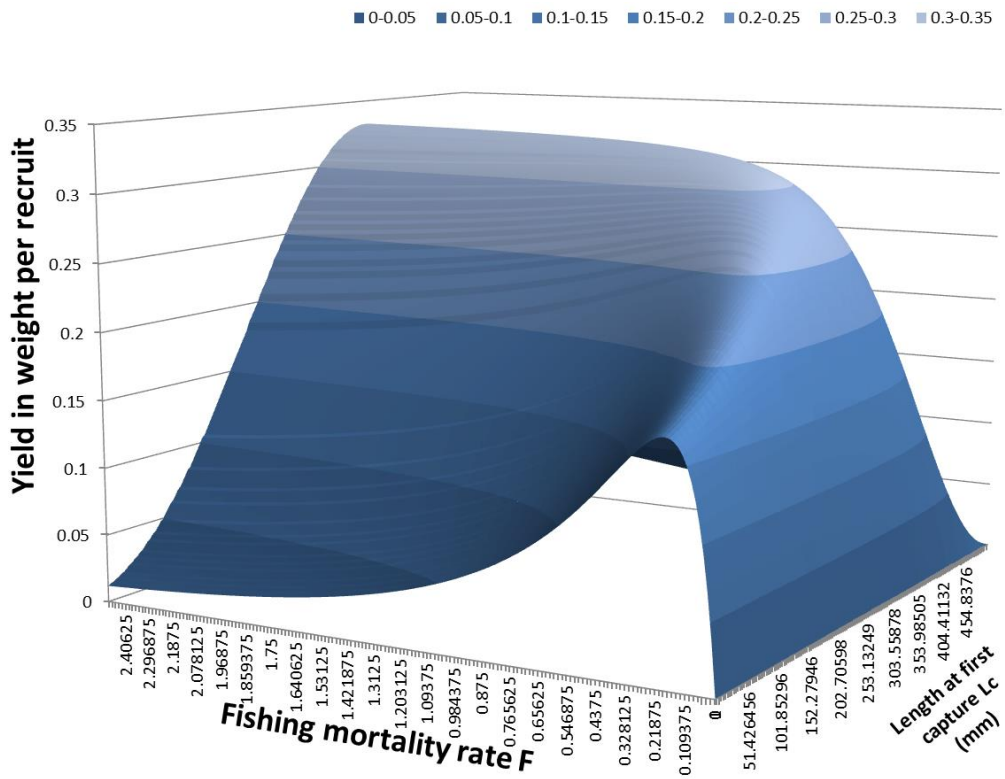


Figure 6.3.3.3: Eumetric line. Calculates the length at first capture that obtains the maximum yield for every potential value of F.

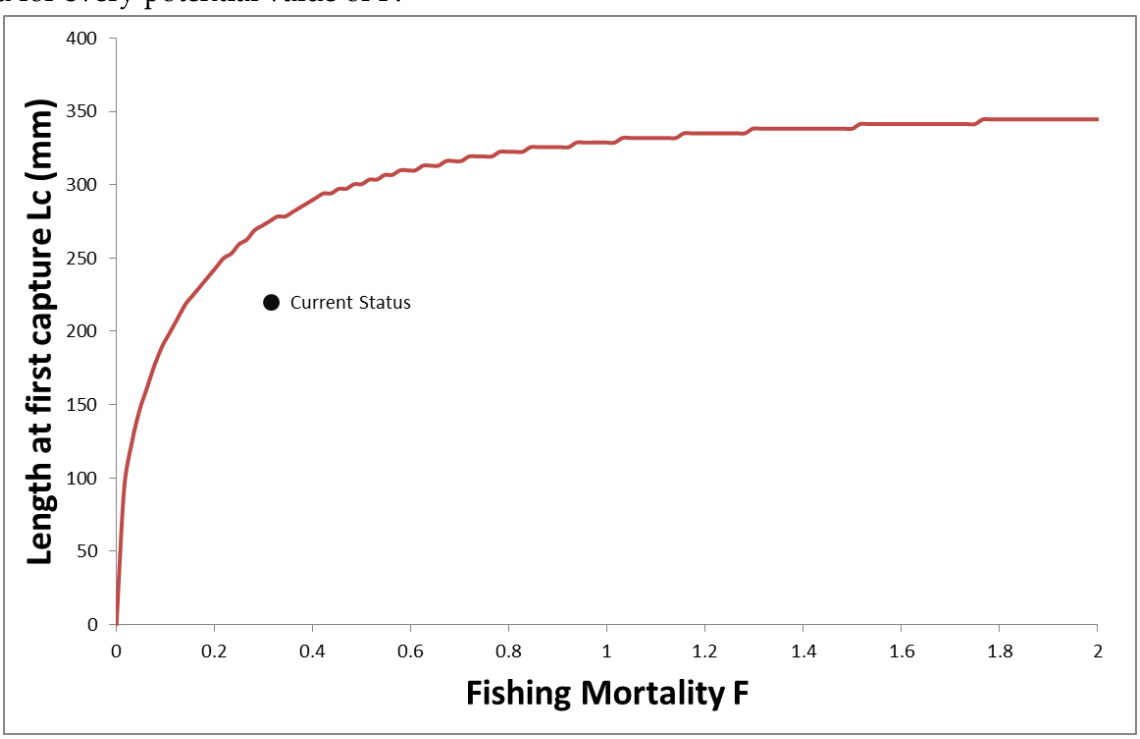


Figure 6.3.3.4: Spawning potential ratio under all conditions of equilibrium F and Lc.

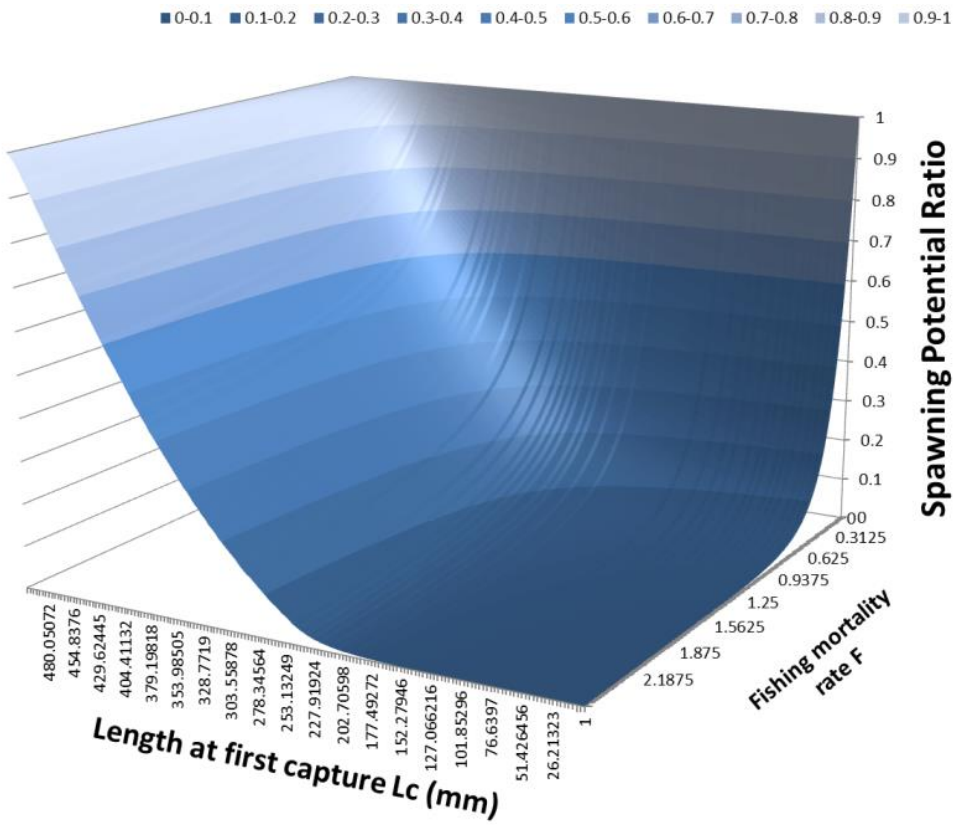
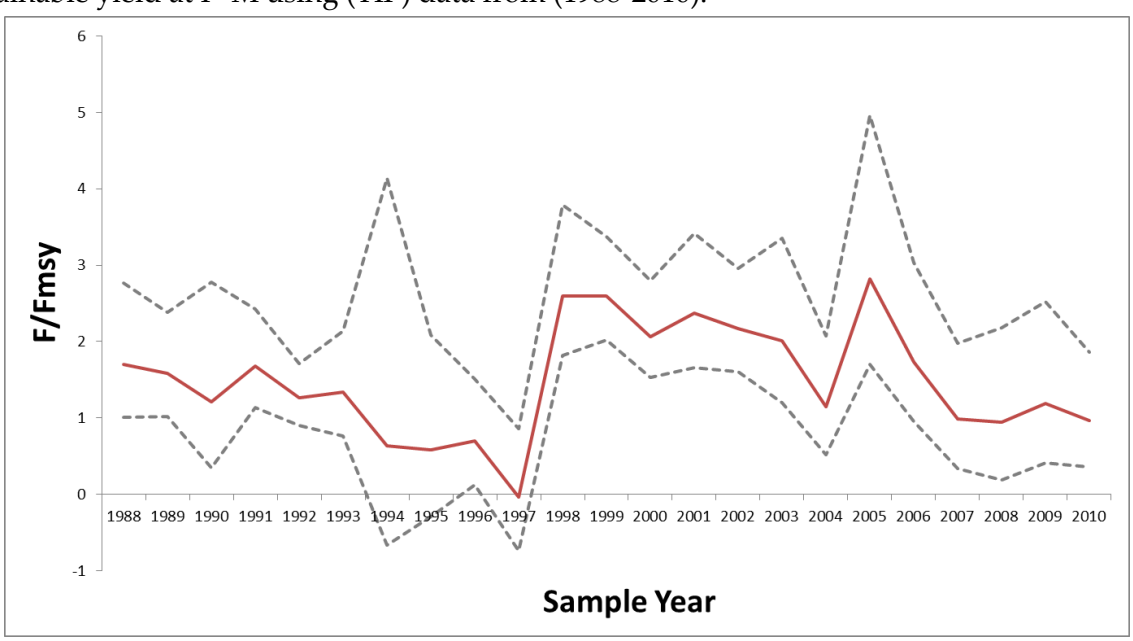


Figure 6.3.3.5: Annual exploitation rate with 95% confidence bounds relative to optimum sustainable yield at F=M using (TIP) data from (1988-2010).



6.3.4 Bluestriped Grunt

Figure 6.3.4.1: Yield per recruit in numbers under all conditions of equilibrium F and Lc.

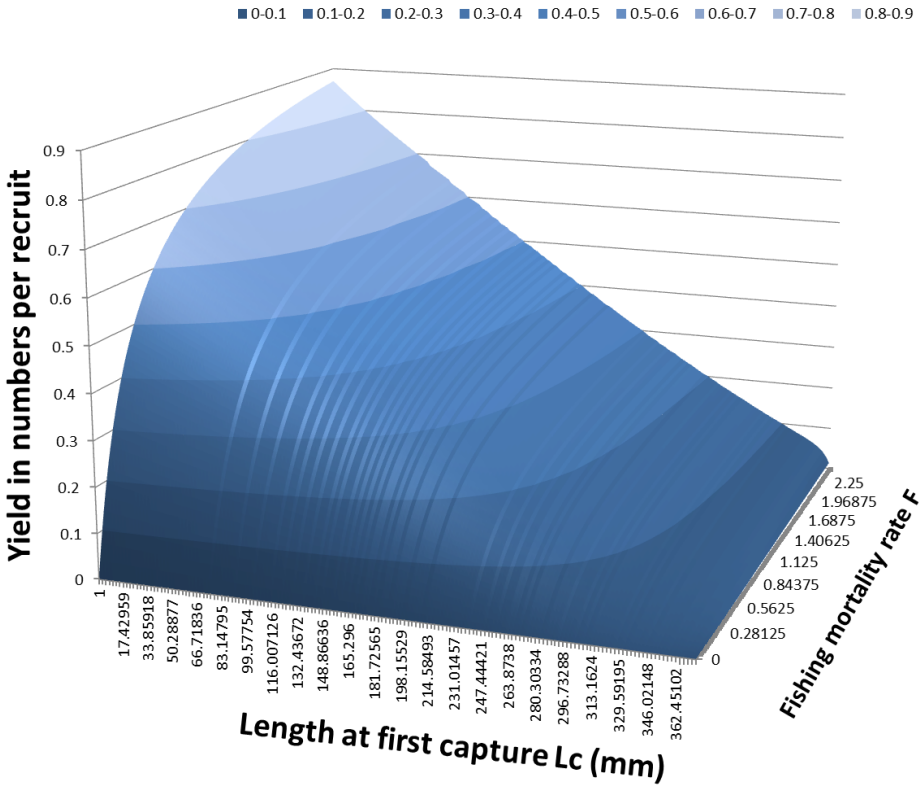


Figure 6.3.4.2: Yield per recruit in weight under all conditions of equilibrium F and Lc.

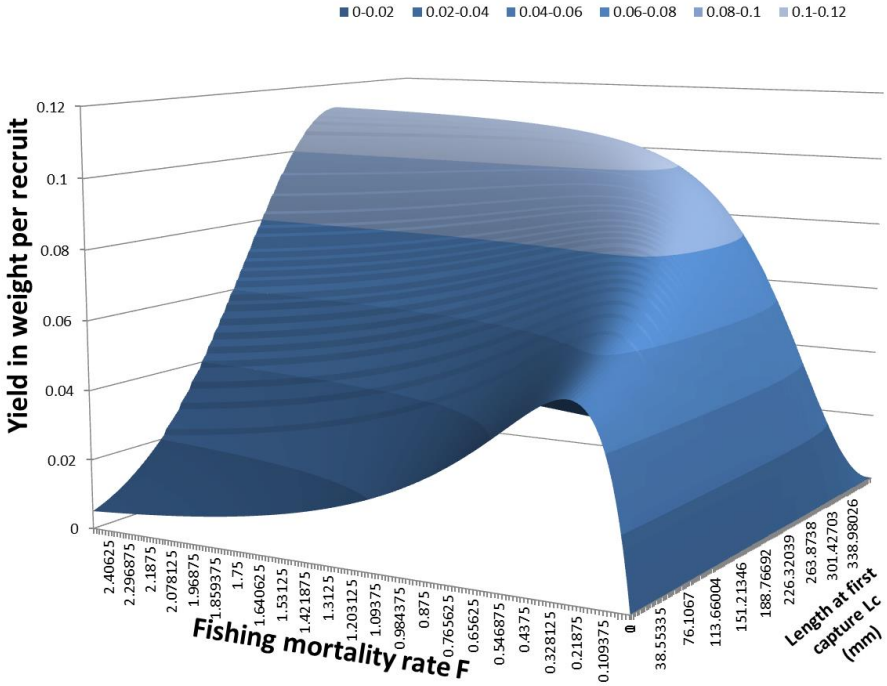


Figure 6.3.4.3: Eumetric line. Calculates the length at first capture that obtains the maximum yield for every potential value of F.

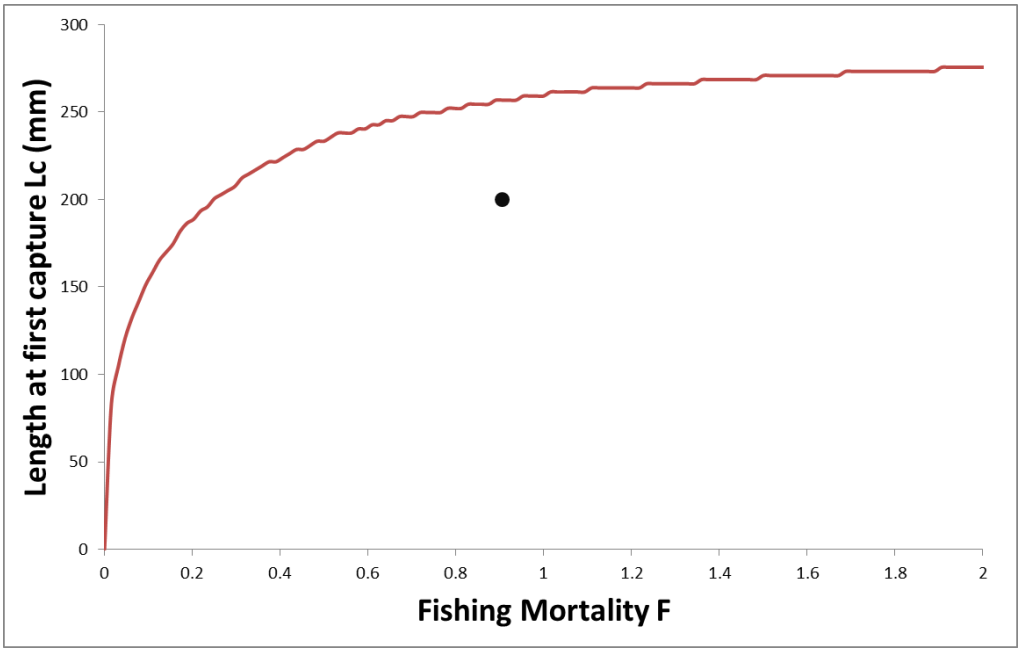


Figure 6.3.4.4: Spawning potential ratio under all conditions of equilibrium F and Lc.

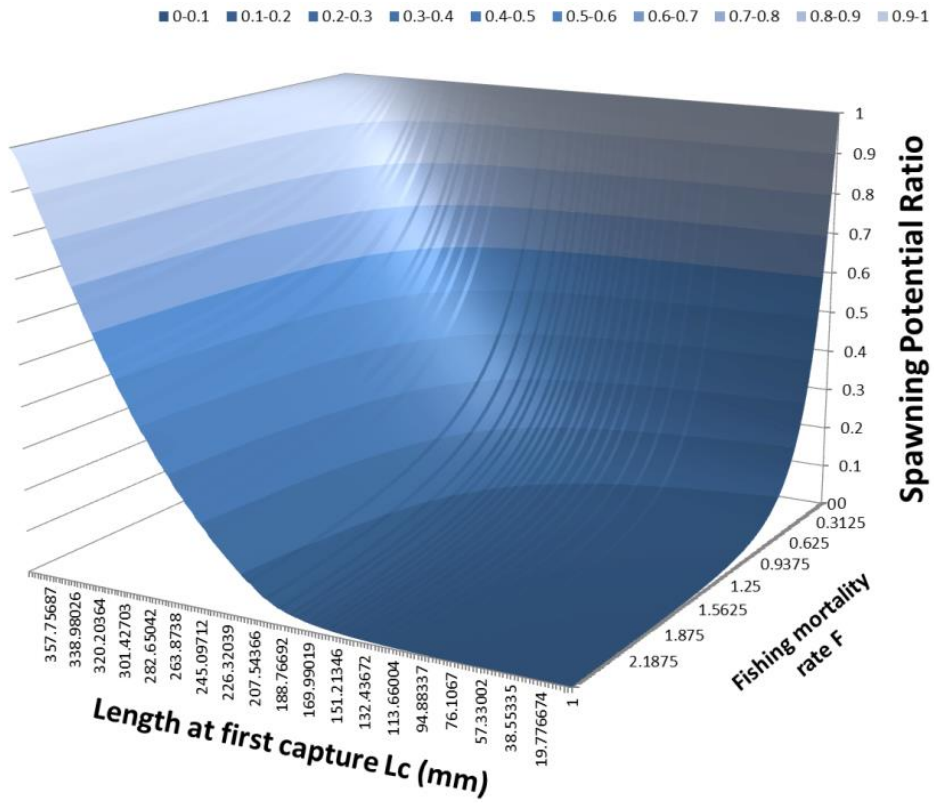
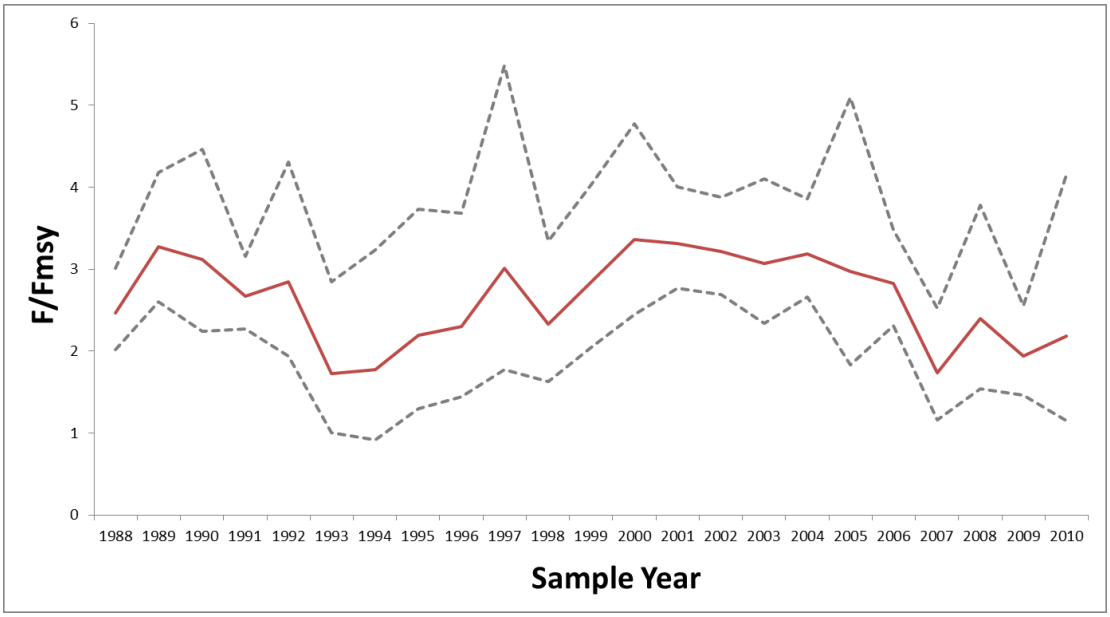


Figure 6.3.4.5: Annual exploitation rate with 95% confidence bounds relative to optimum sustainable yield at F=M using (TIP) data from (1988-2010).



6.3.5 Lane snapper

Figure 6.3.5.1: Yield per recruit in numbers under all conditions of equilibrium F and Lc.

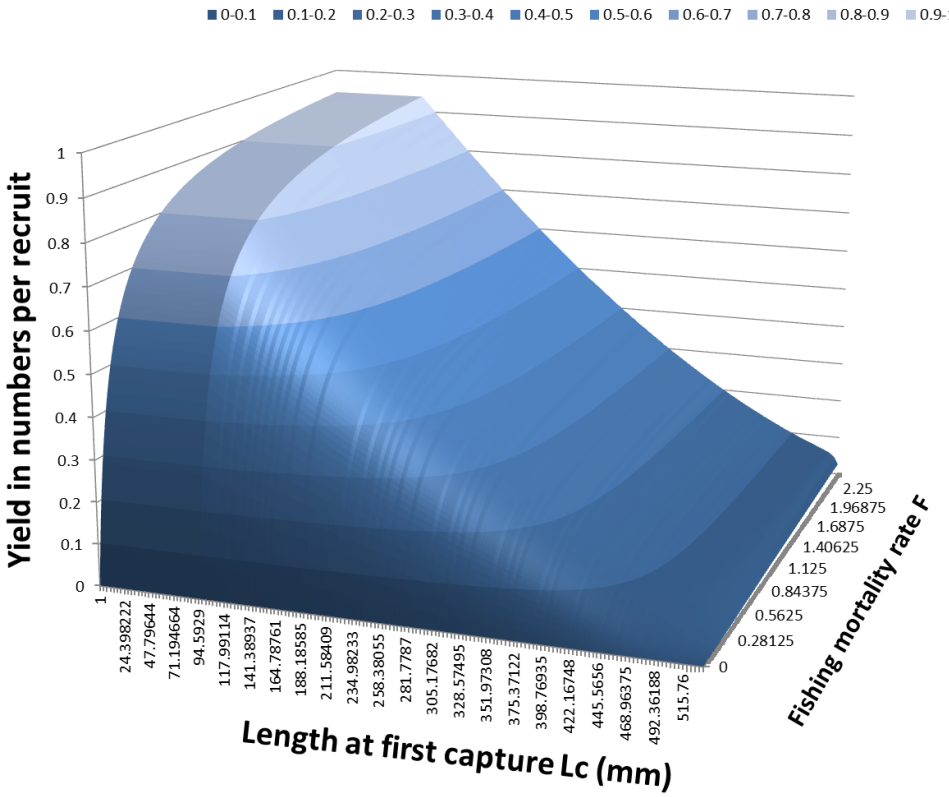


Figure 6.3.5.2: Yield per recruit in weight under all conditions of equilibrium F and Lc.

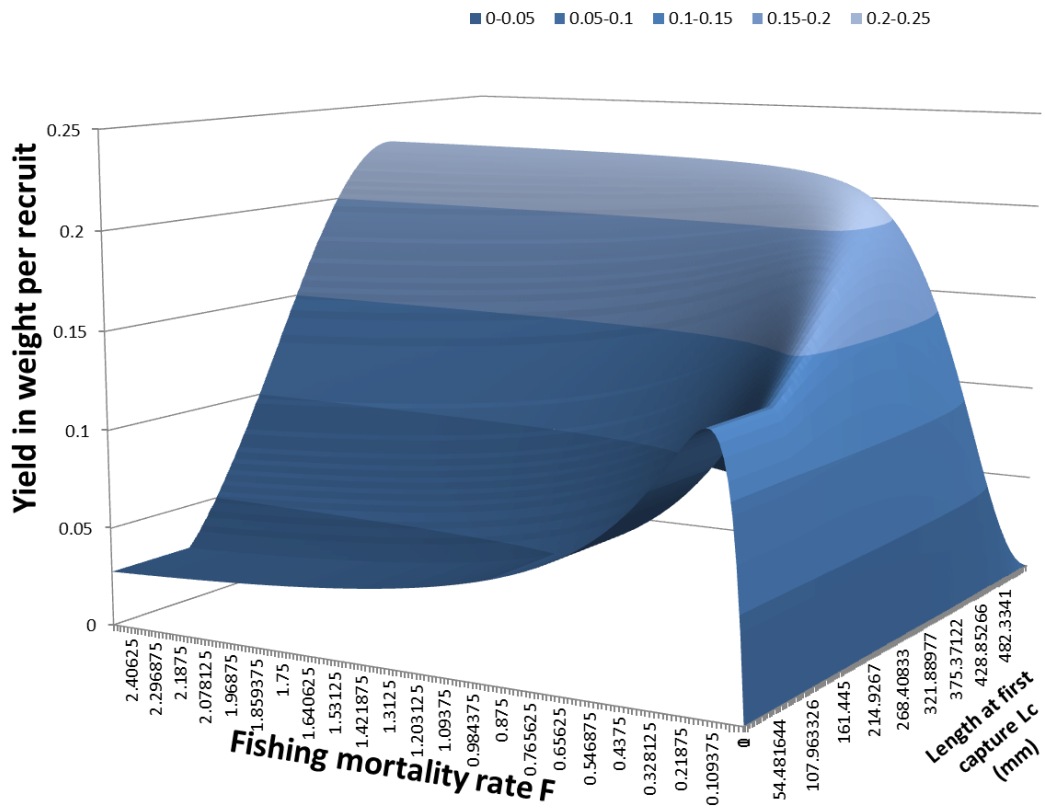


Figure 6.3.5.3: Eumetric line. Calculates the length at first capture that obtains the maximum yield for every potential value of F.

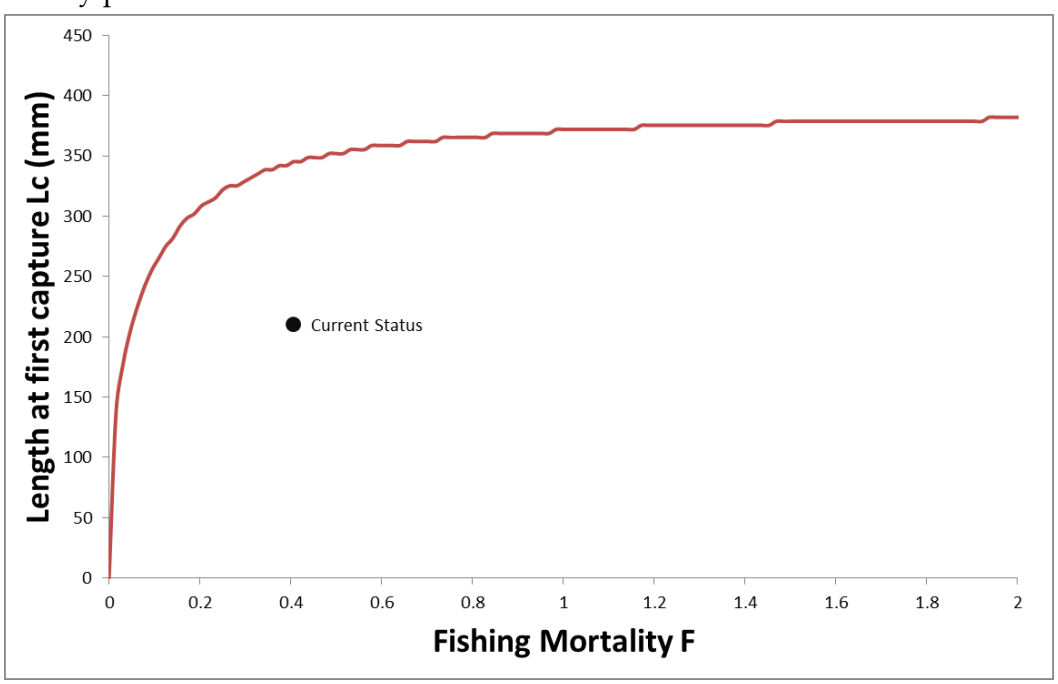


Figure 6.3.5.4: Spawning potential ratio under all conditions of equilibrium F and Lc.

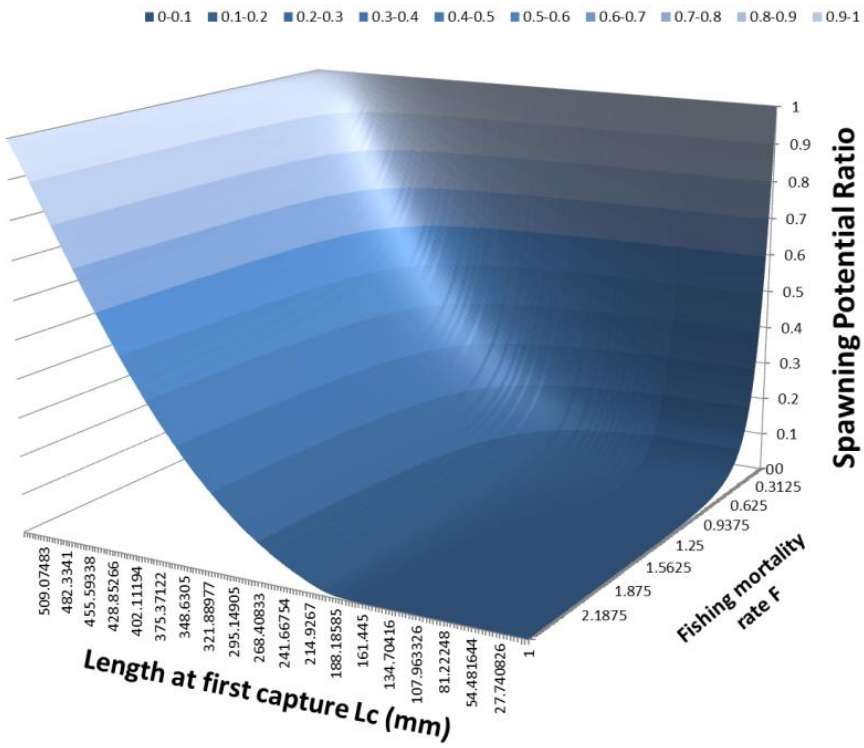
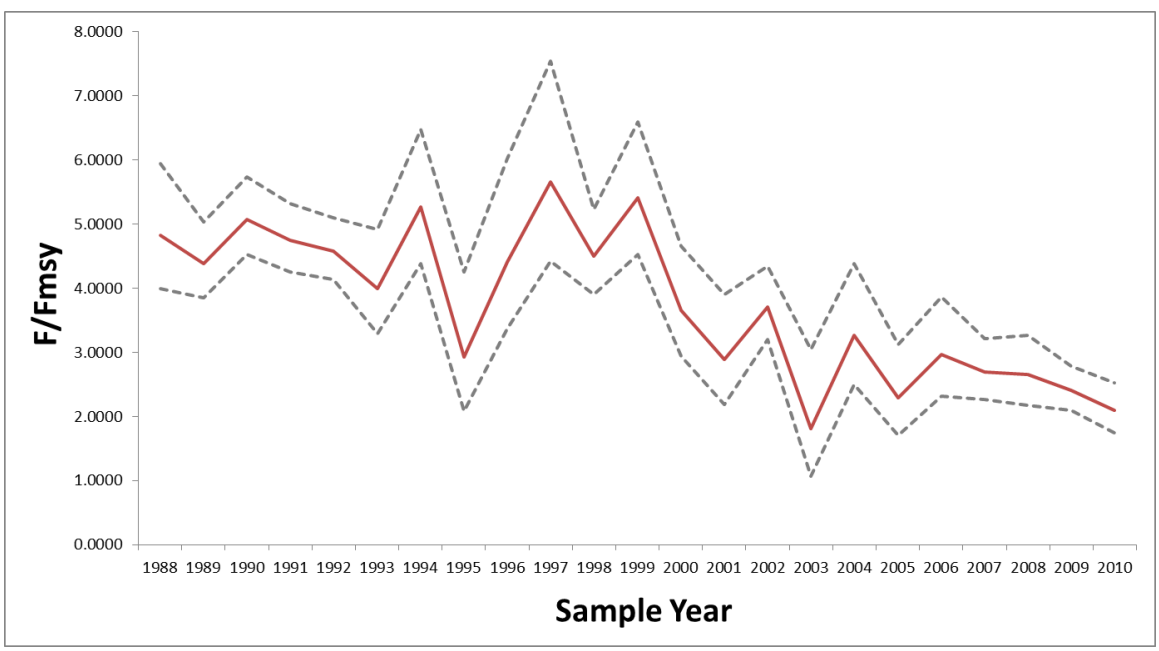


Figure 6.3.5.5: Annual exploitation rate with 95% confidence bounds relative to optimum sustainable yield at F=M using (TIP) data from (1988-2010).



6.3.6 Redtail Parrotfish

Figure 6.3.6.1: Yield per recruit in numbers under all conditions of equilibrium F and Lc.

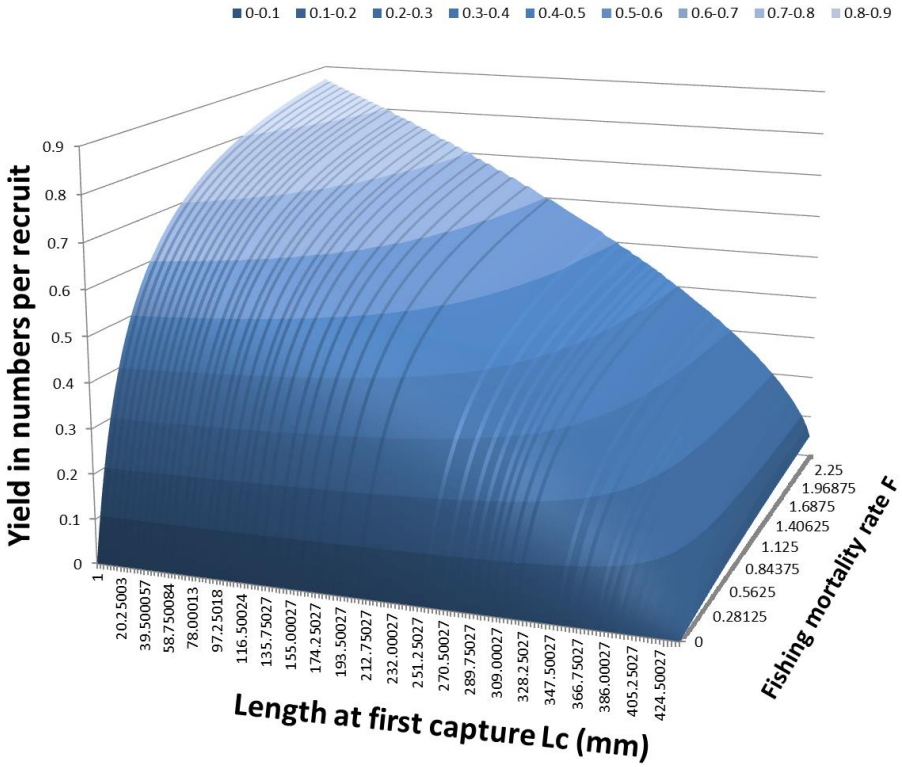


Figure 6.3.6.2: Yield per recruit in weight under all conditions of equilibrium F and Lc.

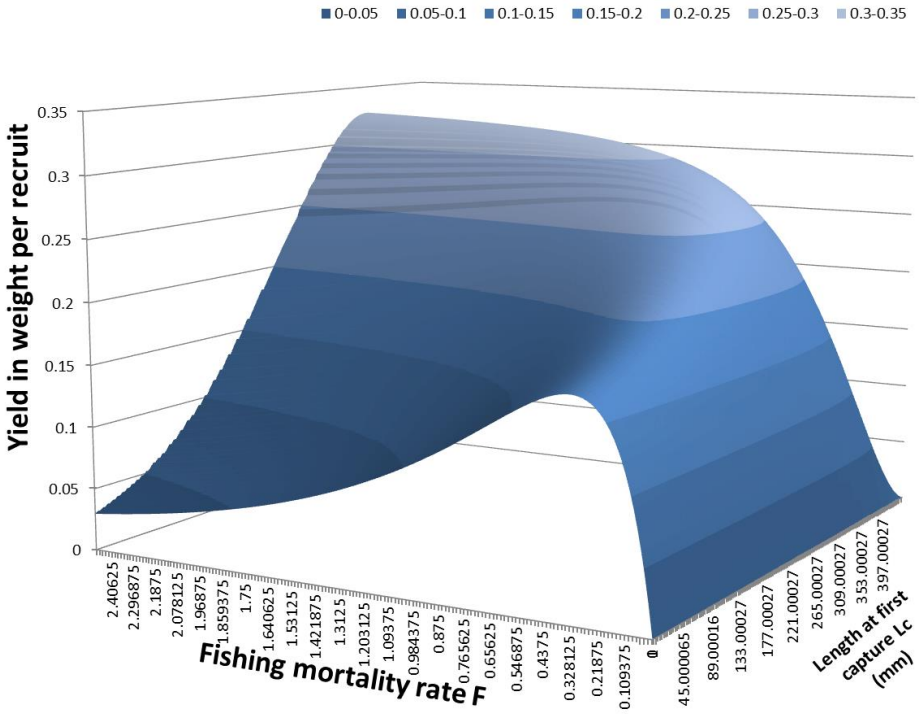


Figure 6.3.6.3: Eumetric line. Calculates the length at first capture that obtains the maximum yield for every potential value of F.

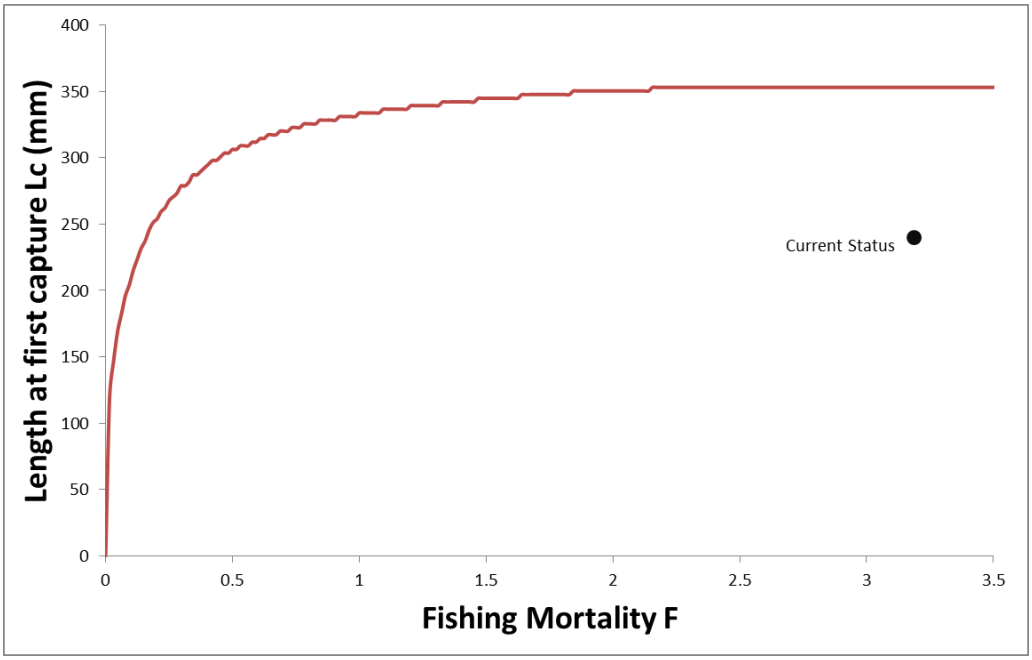


Figure 6.3.6.4: Spawning potential ratio under all conditions of equilibrium F and Lc.

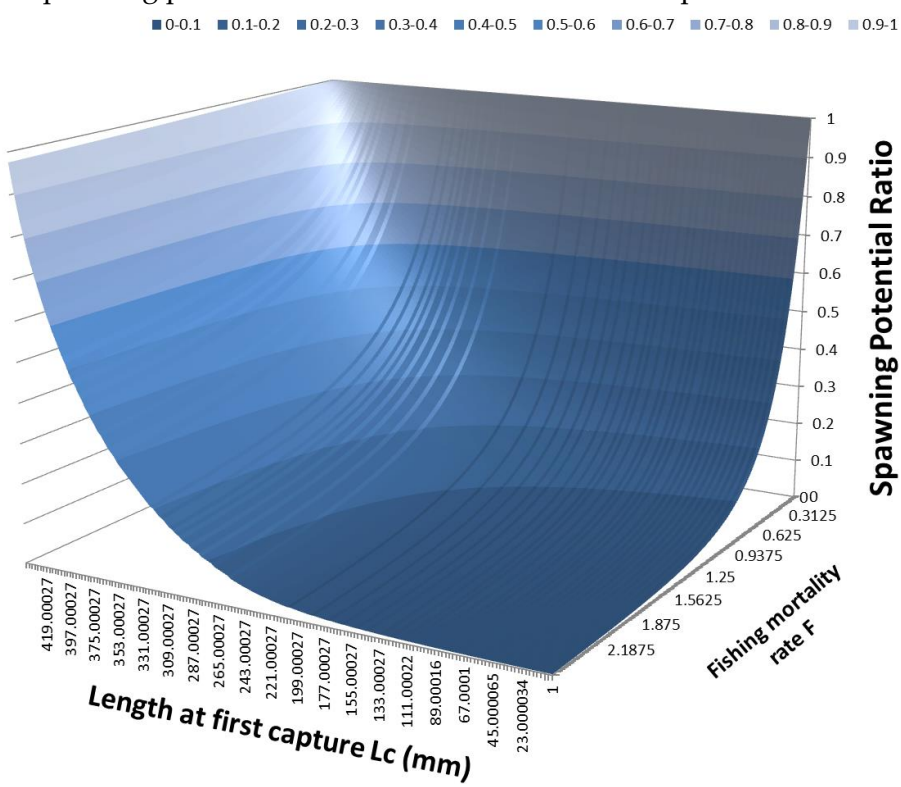
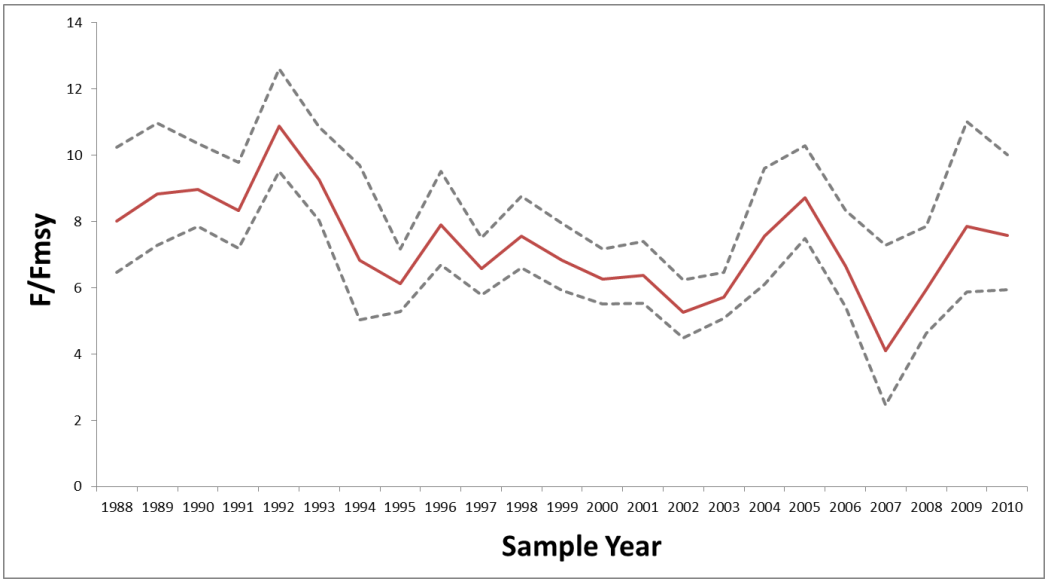


Figure 6.3.6.5: Annual exploitation rate with 95% confidence bounds relative to optimum sustainable yield at F=M using (TIP) data from (1988-2010).



6.3.7 Stoplight Parrotfish

Figure 6.3.7.1: Yield per recruit in numbers under all conditions of equilibrium F and Lc.

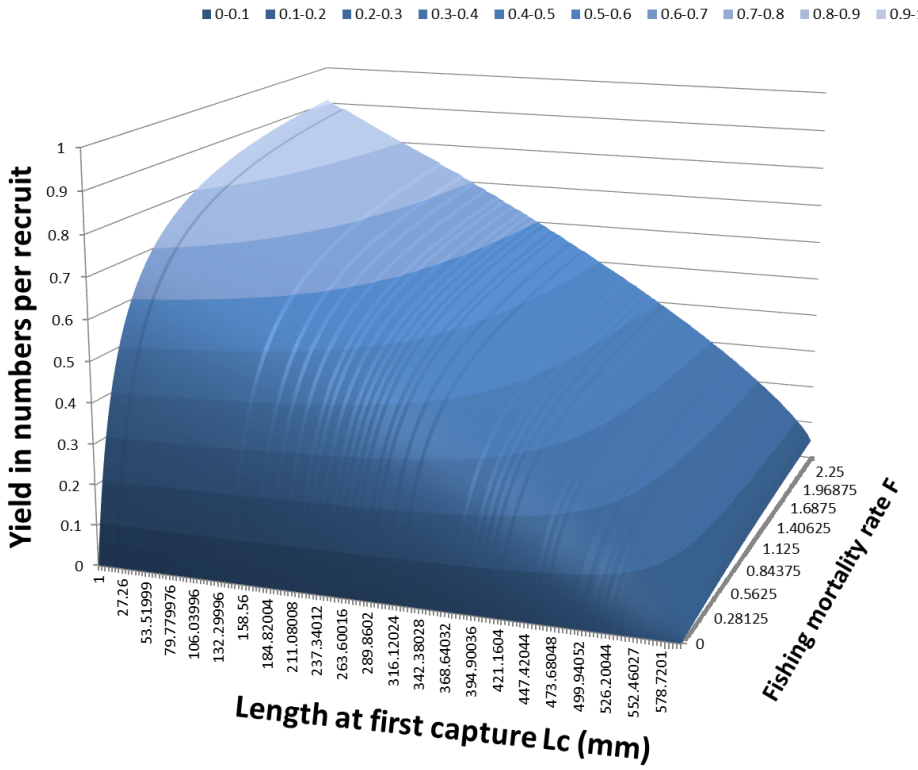


Figure 6.3.7.2: Yield per recruit in weight under all conditions of equilibrium F and Lc.

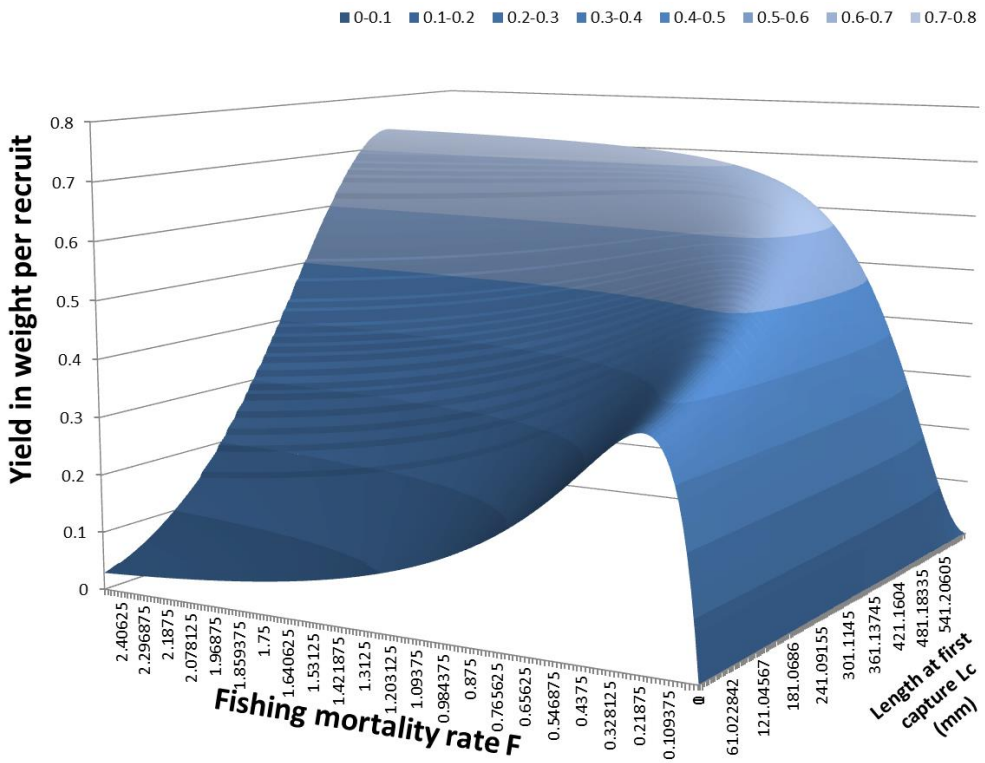


Figure 6.3.7.3: Eumetric line. Calculates the length at first capture that obtains the maximum yield for every potential value of F.

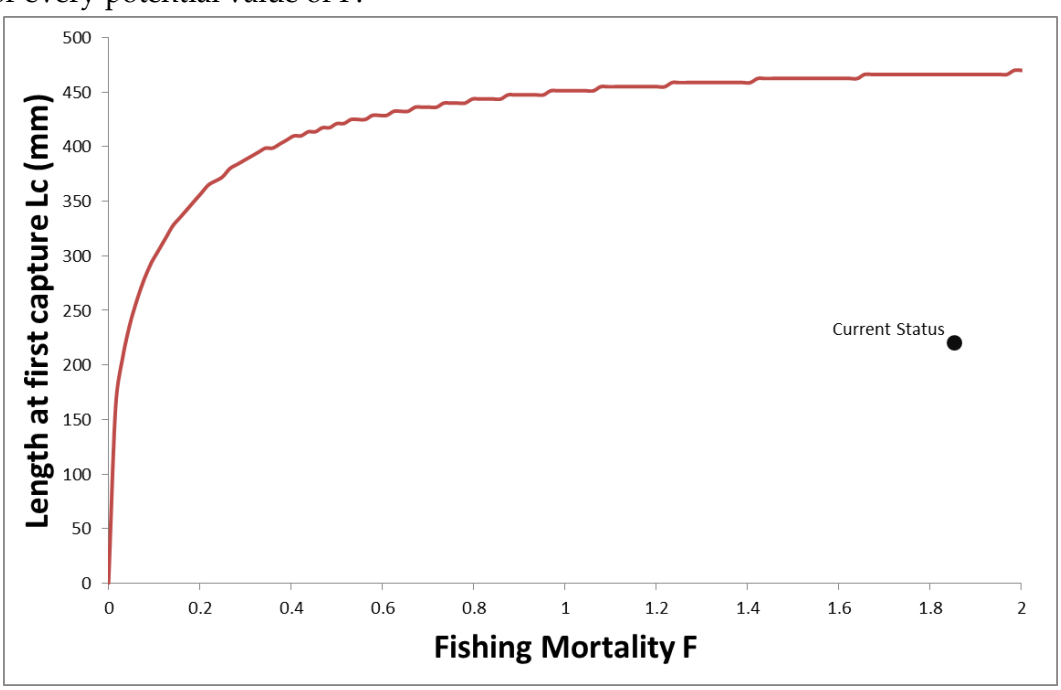


Figure 6.3.7.4: Spawning potential ratio under all conditions of equilibrium F and Lc.

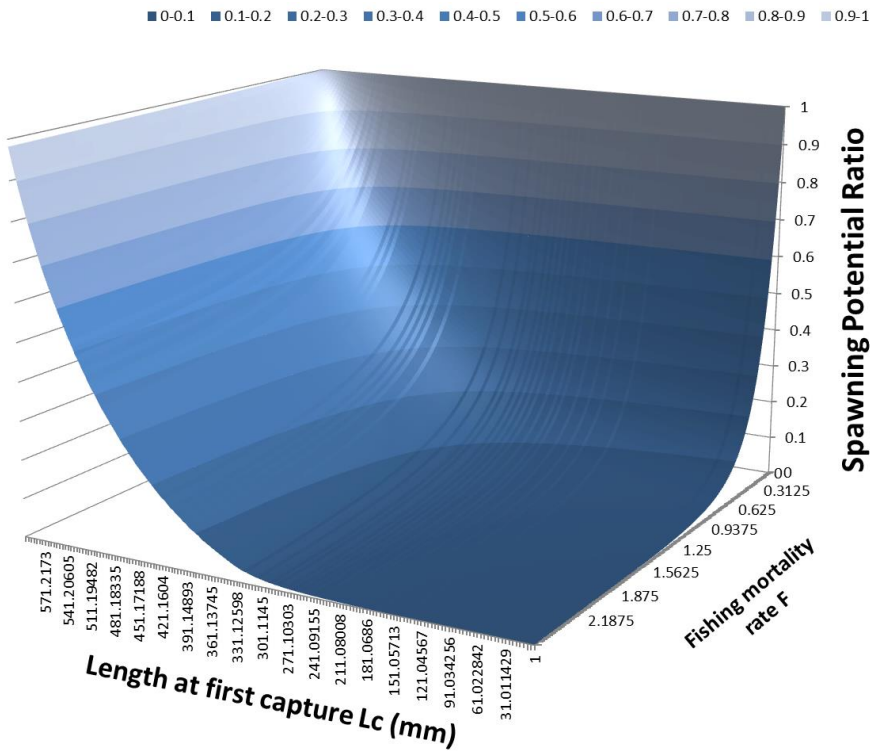
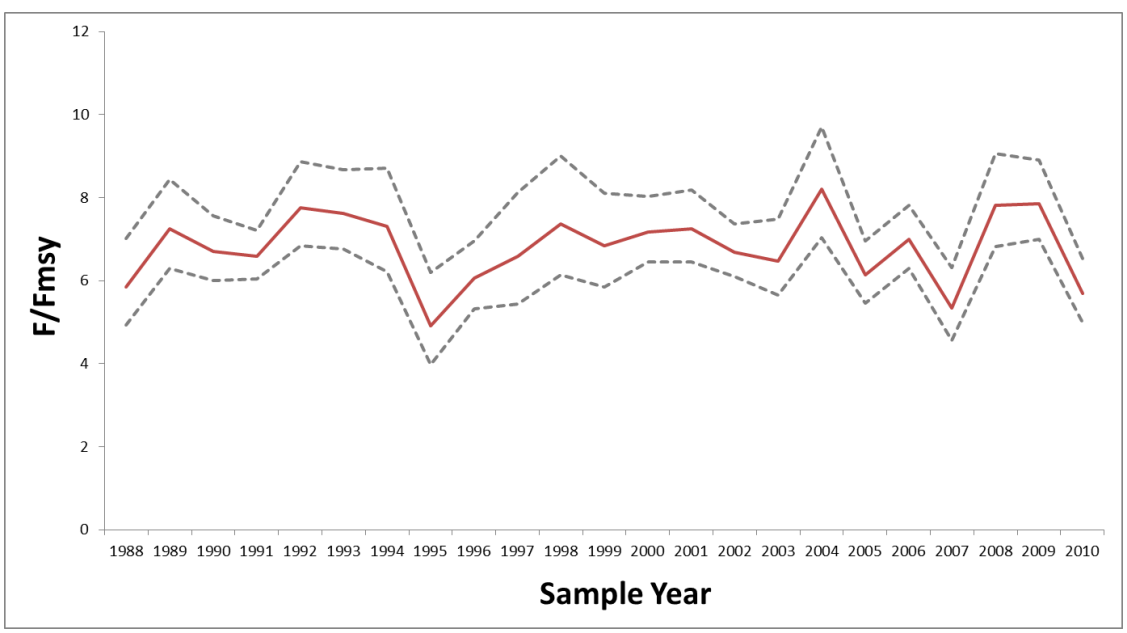


Figure 6.3.7.5: Annual exploitation rate with 95% confidence bounds relative to optimum sustainable yield at F=M using (TIP) data from (1988-2010).



7.0 DISCUSSION & FUTURE OPPORTUNITIES – RECOMMENDATIONS

The results of this assessment continue to support the conclusion that the majority of species in the Puerto Rican fishery are significantly over exploited. These populations will benefit greatly from decreased fishing pressure and increased minimum size of exploitation. There does appear to be evidence that this is occurring organically within the commercial fishery as seen in the TIP data. The retirement of older commercial fishers has not been matched by new entries leading to a consistent decrease in effort, in concert with this a shift in gears from trap to hook and line/spear has taken significant pressure off of the smallest individuals through the inherent differences in gear selectivity pattern. However management action is still required as many species are still highly overexploited. Also of major concern is the recreational fishing fleet, which at present has limited impact but possesses the potential for rapid expansion which would negate and possibly reverse the positive trends being seen from the changing commercial fishery. Particular concern should be given to the parrotfish complex which display extreme overexploitation and the grouper complex which while virtually absent still make intermittent appearance in the catch data suggesting that their populations have already undergone collapse but may once have been as prolific as they are at other locations in the Caribbean.

The following figures (**Figs. 7.1-7.3**) will facilitate discussion of applications of length-based assessment methods to Puerto Rico reef-fishes and future collaborative research opportunities.

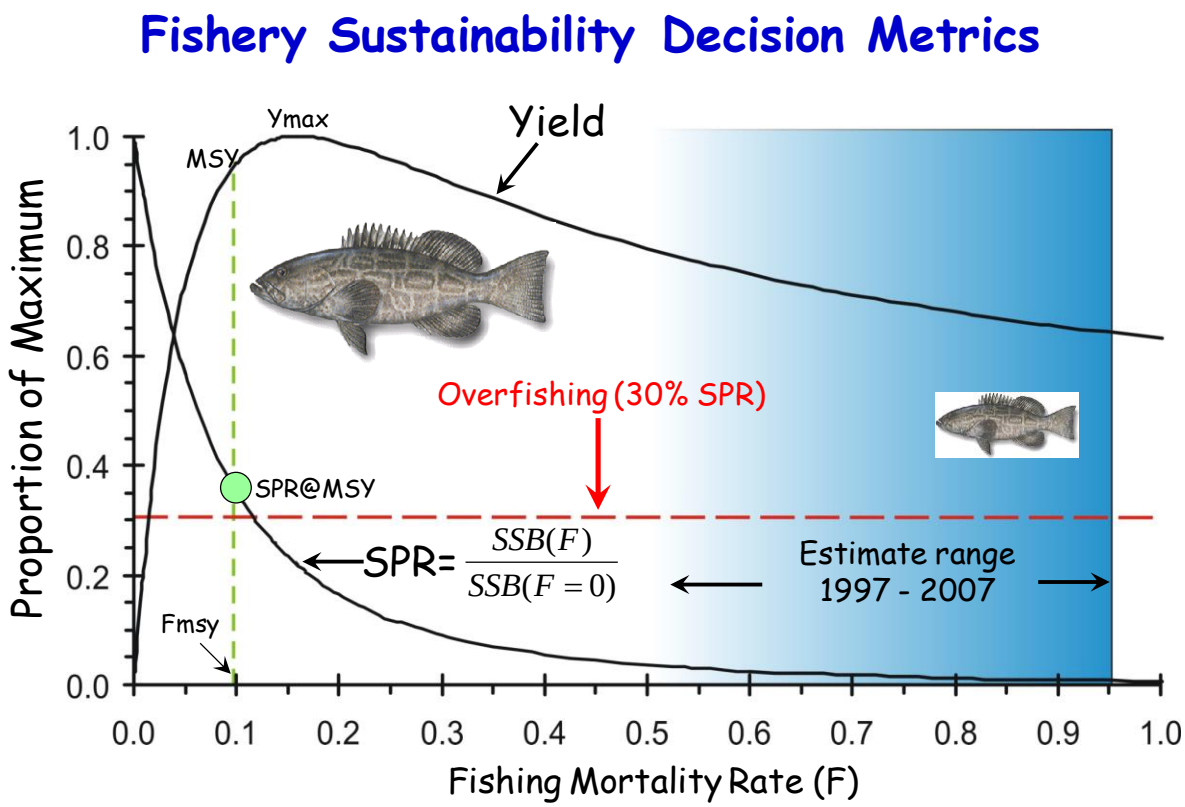


Figure 7.1: YPR and SPR as a function of F.

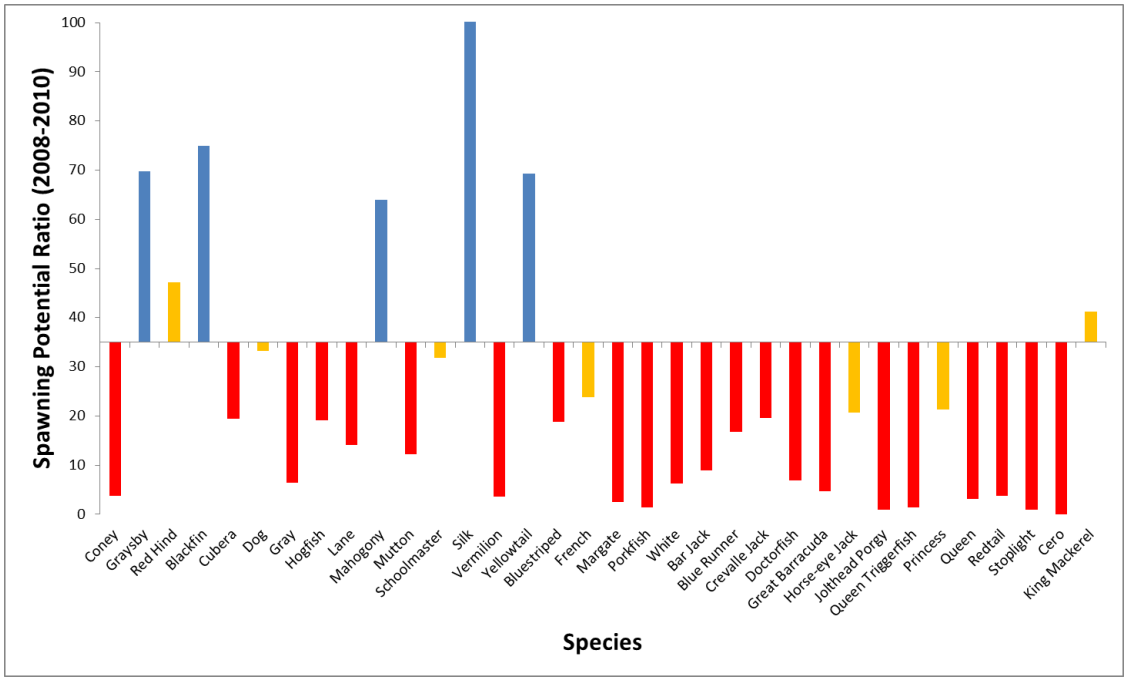


Figure 7.2: Comparative spawning potential ratio (SPR) analysis for 32 exploited reef fish species from the Puerto Rican coral reef ecosystem for the period 2008–2010. Red bars indicate overfished stocks, blue bars indicate stocks that are above the 50% SPR, and yellow bars indicate that stocks are between 20-50% SPR.

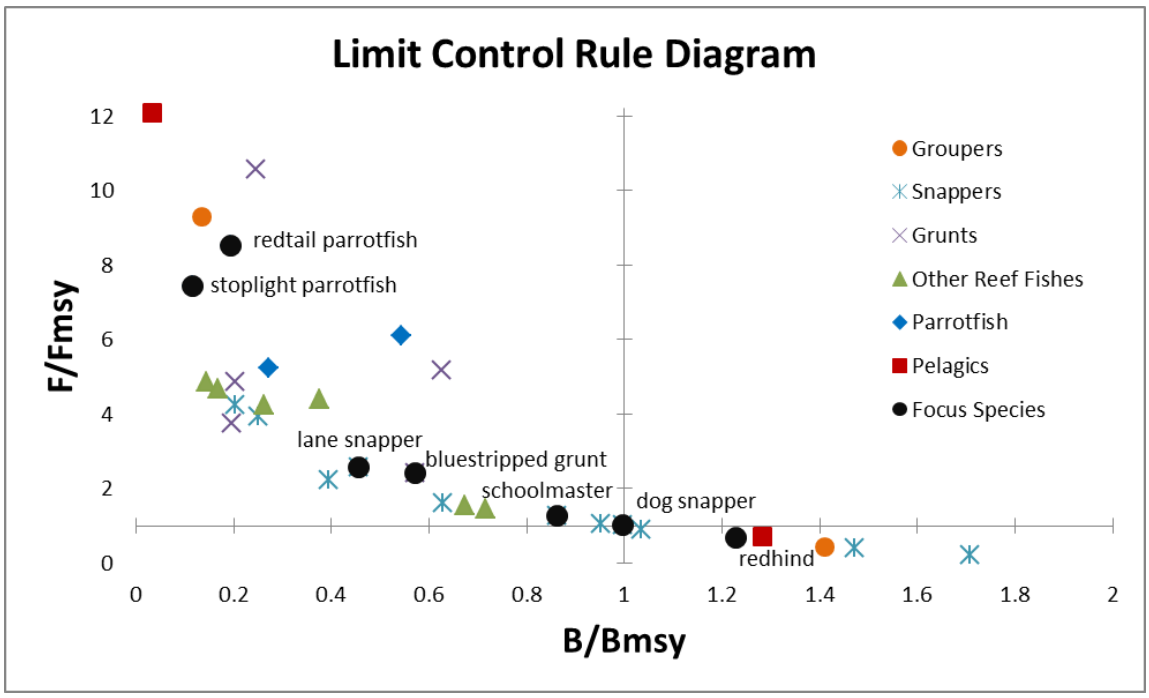


Figure 7.3: F/F_{msy} ratio versus B/B_{msy} ratio for the 32 species analysed for the years 2008–2010.

ACKNOWLEDGEMETNS

We thank Craig Lilyestrom, Puerto Rico Dept of Natural and Environmental Resources, and Aida Rosario and Daniel Matos, DNER Fisheries Research Laboratory, for their astute technical assistance in obtaining fishery-independent and fishery-dependent databases and for managing logistics of the two sets of regional workshops. We also thank Tony Chatwin, Michelle Pico and Erin Duggan of the National Fish and Wildlife Foundation (NFWF) for their support and encouragement of this project. This research was supported by NFWF Grant #2010-004-2000.

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APPENDIX: MAST Model Description & User's Guide

MANUAL FOR MORTALITY ASSESSMENT AND STOCK SIMULATION TOOL (MAST)

Version 1.0 - August 20th, 2011
Authors: Marc Nadon, Nathan Vaughan, Jerry Ault
Programmers: N. Vaughan, M. Nadon
University of Miami, Rosenstiel School of Marine and Atmospheric Science

INTRODUCTION

MASTaggregates all analytical tools necessary for the management of exploited fish populations based on length mortality estimates and presents these in a user-friendly visual interface. MAST is coded in JAVA 7.It is composed of 3 general sections: 1) length-based mortality estimation, 2) theoretical models to find optimal fishing regulations, and 3) exploited population simulator. It will also soon have the capability of running stochastic processes through Monte Carlo simulation in order to evaluate uncertainty and risk associated with management scenarios.

Mortality, maturation, and growth-rates are density-independent (on the recruited population).Recruitment can be either density-independent or -dependent (through a stock-recruitment relationship).

The user interface and mortality estimators were coded by N. Vaughan while the population dynamics models and simulation toolwere mainly coded by M. Nadon, all under the supervision and guidance of Dr. Jerry Ault.

1 -GENERAL INFORMATION

TIMING

All time step computations in MAST are in days (i.e. fish ages and simulated times). All yearly parameters (e.g. K, M, etc.) are automatically converted into daily parameters by dividing by 365 (or other conversion steps). Parameters related to transitional management scenarios (e.g. transitional fishing mortality or minimum size-at-first-capture) are also converted into daily time steps. The daily time steps allow for great flexibility in the specification of maturity, recruitment, and mortality temporal patterns (e.g. seasonal closure, periodic recruitment). However, MAST only currently allows inputs in yearly increments.

MORTALITY

Fish cohorts enter all computational matrices at settlement (i.e. transition from pelagic larvae to bottom- or reef-associated fish). The number of recruits can either be specified through a stock-recruitment relationship or can be fixed at a specific value (see *recruitment* section below). Once the initial number of recruits is specified, MASTcalculates initial number in each daily age group using an exponential mortality formula:

$$N_{t+1} = N_t \cdot e^{-(M+F_t)}$$

Thesestarting N values can be converted toaverage numbers, when needed,using the following equation:

$$\overline{N_t} = \frac{N_t}{M+F} \times (1 - e^{-(M+F_t)})$$

Natural mortality rates are either specified by the user or are derived from estimates of longevity using either a rule-of-thumbs approach that assumes that 1% or 5% of population numbers are left at maximum. This translates into the following general equation:

$$M = \frac{-\ln(S)}{t_\lambda}$$

where S is the survivorship to age t_λ (0.01 or 0.05). A 5% survivorship is a more conservative estimate of natural mortality and is set as the default in MAST.

Fishing mortality *F*is obtained by multiplying the *potential* fishing mortality rate (i.e. the instantaneous mortality coefficient of a fully available age group, which is provided by users) by the gear selectivity *S* which represents the fraction of an age group that is vulnerable to fishing.

$$F_t = q \cdot f \cdot S_t$$

Where q is the catchability coefficient (i.e. proportion of stock caught by a single unit of fishing effort), f is the fishing effort, and S is selectivity at age *t*.Fishing mortalities below minimum age-at-first-capture and above maximum observed-age (i.e. t_λ) are automatically set to zero (knife-edge selection if selectivity is set to 1 for all age groups).

GROWTH

MAST currently only has the option of using the Von Bertalanffy growth equation to determine length-at-age.

$$L_t = L_\infty(1 - e^{-K(t-t_0)})$$

Weight-at-age (W_t) is obtained from converting lengths into weights using the equation:

$$W_t = A \cdot {L_t}^B$$

Important: it is critical to use the proper A and B coefficient for specific length and weight units. Most published A and B values convert length in **cm** into weight in **grams**. MAST will convert those weights into kilograms by dividing by 1000 (all weight, biomass outputs are in kg). We therefore highly recommend inputting all length information in cm (e.g. L_{inf}, L_c, L_{max}, etc.). It is possible to input length information in other units (e.g. mm) if the proper A and B coefficient are used (i.e. those that will output weight in grams).

It is also critical to use the same measurement of fish length for all inputted data (e.g. fork, standard, or total length).

MATURITY

Users can enter either age- or size-at-maturity (MAST will automatically convert one to the other). Maturity is currently set to be knife-edged (i.e. 100% of a cohort reaches maturity at a specific age or size). A logistic curve may be available in future versions, if the need arises.

RECRUITMENT

For simplicity, recruitment levels are often set at a fix value and assumed to be density-independent, especially if spawning stock biomass is known to be at a safe level (SPR > 30%).Alternatively, recruitment can be dependent on spawning stock biomass (SSB).Current recruitment (R_t) is generally assume to be a function of the spawning stock biomass (SSB) at a certain time in the past equivalent to hatching time + pelagic larval stage duration (d).

$$R_t = SSB_{t-d} \cdot f(SSB_{t-d})$$

The Beverton-Holt version of this general equation (Ricker's equation will be available soon) is:

$$R = \frac{SSB}{\alpha + \beta \cdot SSB}$$

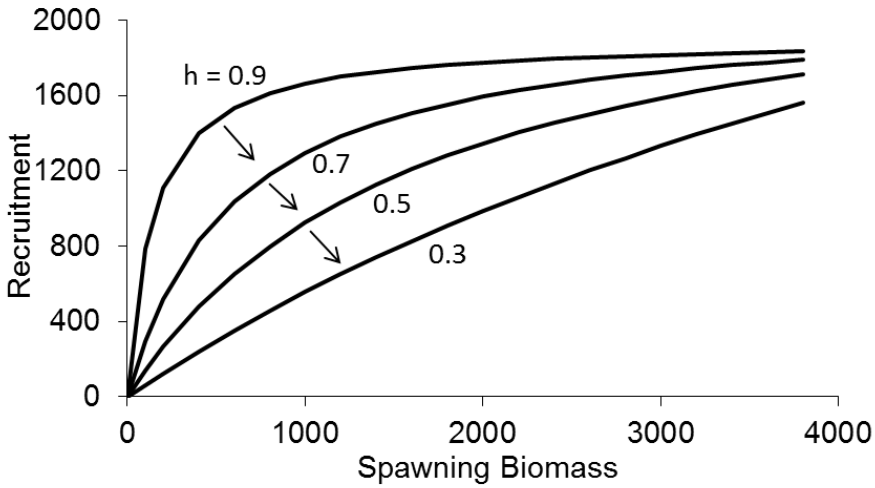
Using Francis (1992)'s re-parameterization,the two parameters of this equation can be defined as

$$\alpha = \frac{B_0(1-h)}{4hR_0} \quad \text{and} \quad \beta = \frac{5h-1}{4hR_0}$$

whereB_0 is an estimate of pristine spawning stock biomass, R_0 is number of recruits at B_0,*h*is the steepness of the initial stock-recruitment curve (i.e. fraction of R_0 corresponding to spawning

stock biomass at 20% B_0). To use this stock-recruitment relationship, users need to define both B_0 and *h*. They also need to input the larval duration in days (i.e. time between spawning event and settlement). Spawning schedule is currently set to be continuous throughout the year, but extra functionality will be added later, with the capability to define recruitment seasonality more precisely.

Below are examples of Beverton-Holt stock-recruitment curves with varying steepness *h*.



2 - LENGTH-BASED MORTALITY ESTIMATION

BEVERTON-HOLT MODEL

Beverton and Holt (1954) were the first to derive an equation relating average length in the catch (Lbar) to total mortality (Z).

$$\overline{L} = \frac{\int_{t_c}^{t_\infty} F_t \cdot L_t \cdot N_t \cdot dt}{\int_{t_c}^{t_\infty} F_t \cdot N_t \cdot dt} \quad \rightarrow \quad Z = \frac{K \cdot (L_\infty - \overline{L})}{(\overline{L} - L_c)}$$

However, Ehrhardt and Ault (1992) found this model to be biased because of the integration to infinite age (i.e. influenced by theoretical, very old, fish that are never present in catch records). This model is not available in MAST due to this problem.

AULT-EHRHARDT MODEL

Ault and Ehrhardt (1991) proposed a truncated version of the Beverton-Holt model that sets a realistic upper limit for maximum lengths (L_{max} or L_λ). As such, this model takes an extra parameter (t_λ or L_λ).

$$\overline{L} = \frac{\int_{t_c}^{t_\lambda} F_t \cdot L_t \cdot N_t \cdot dt}{\int_{t_c}^{t_\lambda} F_t \cdot N_t \cdot dt} \quad \rightarrow \left(\frac{L_\infty - L_\lambda}{L_\infty - L_c}\right)^{Z/k} = \frac{Z\left(L_c - \overline{L}\right) + K(L_\infty - \overline{L})}{Z\left(L_\lambda - \overline{L}\right) + K(L_\infty - \overline{L})}$$

This model does not have the same bias as the Beverton-Holt model, but, as with the B-H model, it does assume equilibrium conditions (i.e. stable recruitment and mortalities during a time period long enough for stock age structure to be stable).

VAUGHAN-AULT MODEL

An improved model is currently under development that will be able to deal with non-equilibrium mortality conditions. This model will merge the size-truncated model of Ehrhardt and Ault (1992) with the non-equilibrium model develop by Gedemke-Hoenig (which is based on the Beverton-Holt model and thus suffers from the same potential bias). This tool is not currently available in MAST 1.0.

3 - THEORETICAL MODELS USED TO ESTIMATE OPTIMAL MANAGEMENT REGULATIONS

Once current fishing mortality rates are estimated, it is possible to parameterize various models in order to estimate current stock status and preferable management targets. If recruitment is set at a fix level, users can run yield-per-recruit (YPR) and spawning potential ratio (SPR) analyses. If a stock-recruitment function is defined, users can run models in terms of absolute yield, which take the effect of reduced spawning stock biomass on recruitment (and yield) into account. These models all assume that a population has reached equilibrium.

YIELD-PER-RECRUIT

MAST calculates YPR in "piece-wise" fashion by applying the mortality equations defined above to a fixed number of recruits (e.g. 1000) all the way to maximum age (t_λ), using daily increments. YPR is calculated at each daily age by multiplying average biomass by fishing mortality F, summing all daily yields, and dividing by the original number of recruits.

$$YPR = \frac{1}{Recruits} \sum_{t=0}^{t_\lambda} F_t \cdot \overline{N}_t \cdot \overline{W}_t \cdot$$

YPR is calculated for a large number of combinations of length-at-first-capture (L_c) and fishing mortality rates (F). Specifically, YPRsare calculated from L_c = 1 cm to L_{max} in L_{max}/100 increments, and from F = 0 to 2.5 in increments of 0.025. The YPRs for all these combinations are exported from MAST and can be plotted in Excel or other software (see examples at the end of this section).

SPR

MAST calculates spawning potential ratio (SPR) in a similar way as for YPR. Biomass is calculated at each daily age and spawning stock biomass is simply the sum of all biomass above the age at maturity.Spawning stock biomass is calculated as

$$SSB = \sum_{t=t_m}^{t_\lambda} \overline{N}_t \cdot \overline{W}_t$$

whereW_t is the average weight-at-age. Spawning stock biomass is calculatedat pristine levels (B_0) and under various management scenarios (L_c, F), similarly to YPR. SPR is then calculated for different levels of L_c and F by dividing spawning stock biomass under exploitation by pristine spawning stock biomass.

$$SPR = \frac{SSB_F}{SSB_{F=0}}$$

SPR isopleth graphs can be produced from the MAST output, similarly to YPR isopleth (see example below).

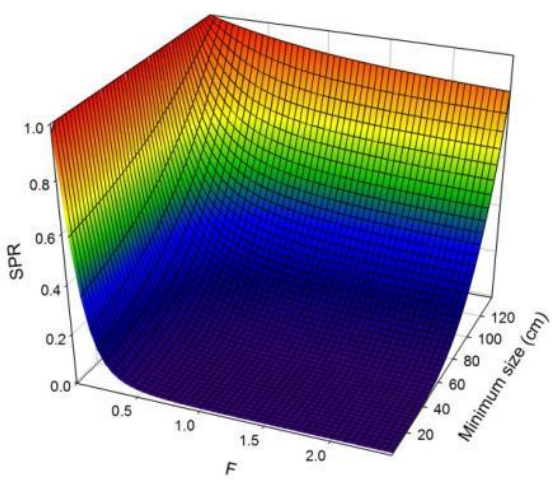
ABSOLUTE YIELD WITH VARIABLE RECRUITMENT

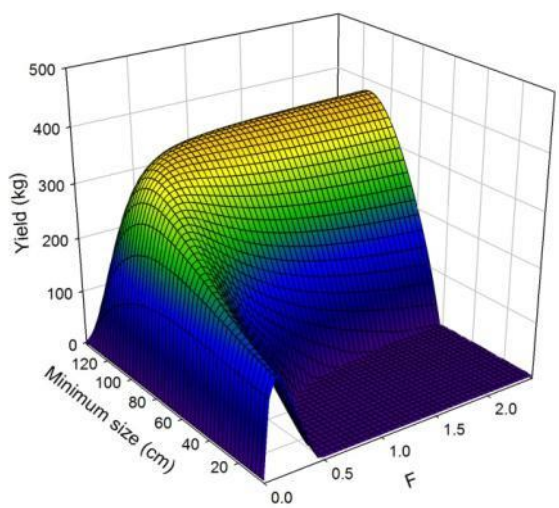
If a recruitment function is defined, yield can be calculated in absolute terms. MAST first calculates the number of recruits entering the population under equilibrium conditions (i.e. for specific L_c and F values). The following equation is used

$$R_e = \frac{SSB_e - \alpha}{\beta \times SSB_e}$$

whereα and β are parameters of the Beverton-Holt stock-recruitment equation. From the equilibrium recruitment level, the structure of the population at equilibrium is derived from which absolute yield can be calculated.As for YPR and SPR, absolute yield is calculated for various combinations of L_c and F and can be plotted in Excel.

Below are examples of SPR (left) and absolute yield (right) graphs created in SigmaPlot.





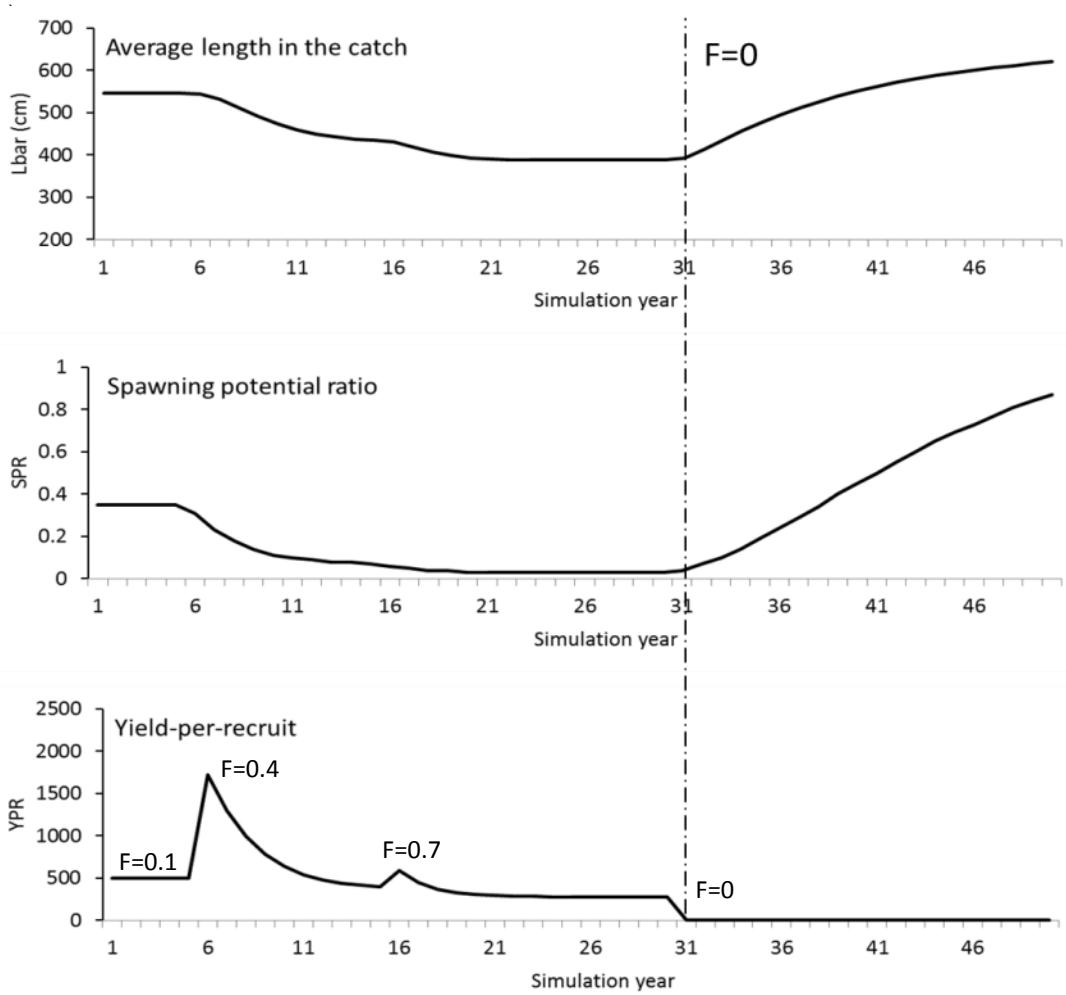
4 - EXPLOITED POPULATION SIMULATION

MAST includes population simulation capabilities which allow users to track Lbar, yield, or SPR forward through time in daily time steps according to various management scenarios (i.e. L_c and/or F changing at various times). To use this tool, users need to provide vectors of expected 'future' yearly changes in F and L_c.

The simulation can be run with fixed recruitment, set at a specified level. It can also be run with a stock-recruitment function after specifying pristine spawning stock biomass (B_0),steepness (h), and pelagic larvae duration.

Note: MAST is capable of running population simulations forward through time for a (theoretically) unlimited number of daily time steps, given some basic computer memory capacity (i.e. at least 256 mb). MAST determines available memory to JAVA and divides the simulation task in manageable blocks. The more memory a computer has, the larger the time blocks and the faster the simulation will run through completion.

Below is an example of a MASTsimulation output based on Mutton snapper life history (L_c = 300 m



Sustaining Coral Reef Fisheries of Puerto Rico

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Report of Technical Workshop #3
May 2014

Fisheries Technical Workshop #3
"Building Fisheries Information Systems for Sustaining Coral Reef Fisheries of Puerto Rico"

Conveners: Drs. Jerry Ault and Steve Smith, University of Miami's Rosenstiel School of Marine and Atmospheric Science.

Local Host: Dr. Craig Lilyestrom, Puerto Rico Dept. of Natural and Environmental Resources

Location: DNER, San Juan: May 19-20, 2014.

Introduction.- The coral reef fisheries of the Puerto Rico reef ecosystem support multimillion-dollar fishing and tourism industries. The sustainability of these fisheries is a key conservation concern given their economic and ecological importance, the significant dependence of subsistence and artisanal fishers on reef fisheries for their livelihoods, and the considerable and growing threats to coral reef habitats (i.e. coral bleaching and disease, pollution and climate change). Sustainability refers to the ability of an exploited stock to produce goods and services, including yields at suitable levels in the short term, while maintaining sufficient stock reproductive capacity to continue providing these goods and services into the indefinite future. The data- and model-limited situations confronting most coral reef fisheries, including those of Puerto Rico, have hampered application of modern stock assessment techniques that meet the legal mandate of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). Technical Workshops #1 and #2, conducted in May and September 2013, focused on the theory and application of length-based methods for stock assessment of data-limited fisheries in Puerto Rico. These methods were applied to 34 reef-associated species that had sufficient length composition and life history data to assess current sustainability status. Additionally, in-depth assessments of changes in sustainability status over the past 23 years were conducted for seven focus species: red hind, dog snapper, schoolmaster, bluestriped grunt, lane snapper, redtail parrotfish, and stoplight parrotfish. Collaborating scientists and managers from the Puerto Rico Department of Natural and Environmental Resources (DNER) subsequently developed a suite of fishing regulations, including gear and size restrictions, to correct overfishing problems identified in Technical Workshops #1 and #2. These regulations are pending final legal approval.

Another outcome of Technical Workshops #1 and #2 was the identification of critical data needs to support future assessment and management of coral reef fisheries in Puerto Rico. Addressing these data needs became the focus of Technical Workshop #3.

Workshop Goal:- The goal of Technical Workshop #3 was reflected in its title, "Building Fisheries Information Systems for Sustaining Coral Reef Fisheries of Puerto Rico".

Workshop Objectives:- The objectives of Technical Workshop #3 were twofold: (1) to create a more accessible database for information on recreational fishing in Puerto Rico; and (2) to prioritize key additional data needs and to discuss strategies for addressing these needs over the next several years. Accomplishments for these two objectives are described in the following sections.

Accessible Database for Recreational Fishing:- Collaborating researchers from UM and DNER developed data processing procedures and associated computer code for creating a more accessible database for the Marine Recreational Fisheries Statistical Survey (MRFSS) in Puerto Rico, the primary sampling program for the recreational fishing fleet which began in 2000. The intercept survey form for recreational fishers in Puerto Rico is provided in the Appendix. A relational database for MRFSS data for Puerto Rico was designed using Microsoft Access. Researchers at the University of Miami (UM) and DNER collaborated on compiling the various tables describing codes for key variables such as species, Municipios, site locations, fishing gears, etc. UM researchers developed data processing procedures using SAS statistical software to transform the NOAA MRFSS data into the various key data tables for Puerto Rico. The overall processing flow is illustrated in the diagram of **Fig. 1.** The three primary relational data tables for trip, catch, and length-weight information are respectively described in **Tables 1**, **2** , and **3**.

Figure 1. Processing flow diagram for transforming NOAA's database for the Marine Recreational Fisheries Statistical Survey for Puerto Rico into a user-friendly relational database in Microsoft Access. The processing procedures utilize SAS statistical software and Microsoft Excel.

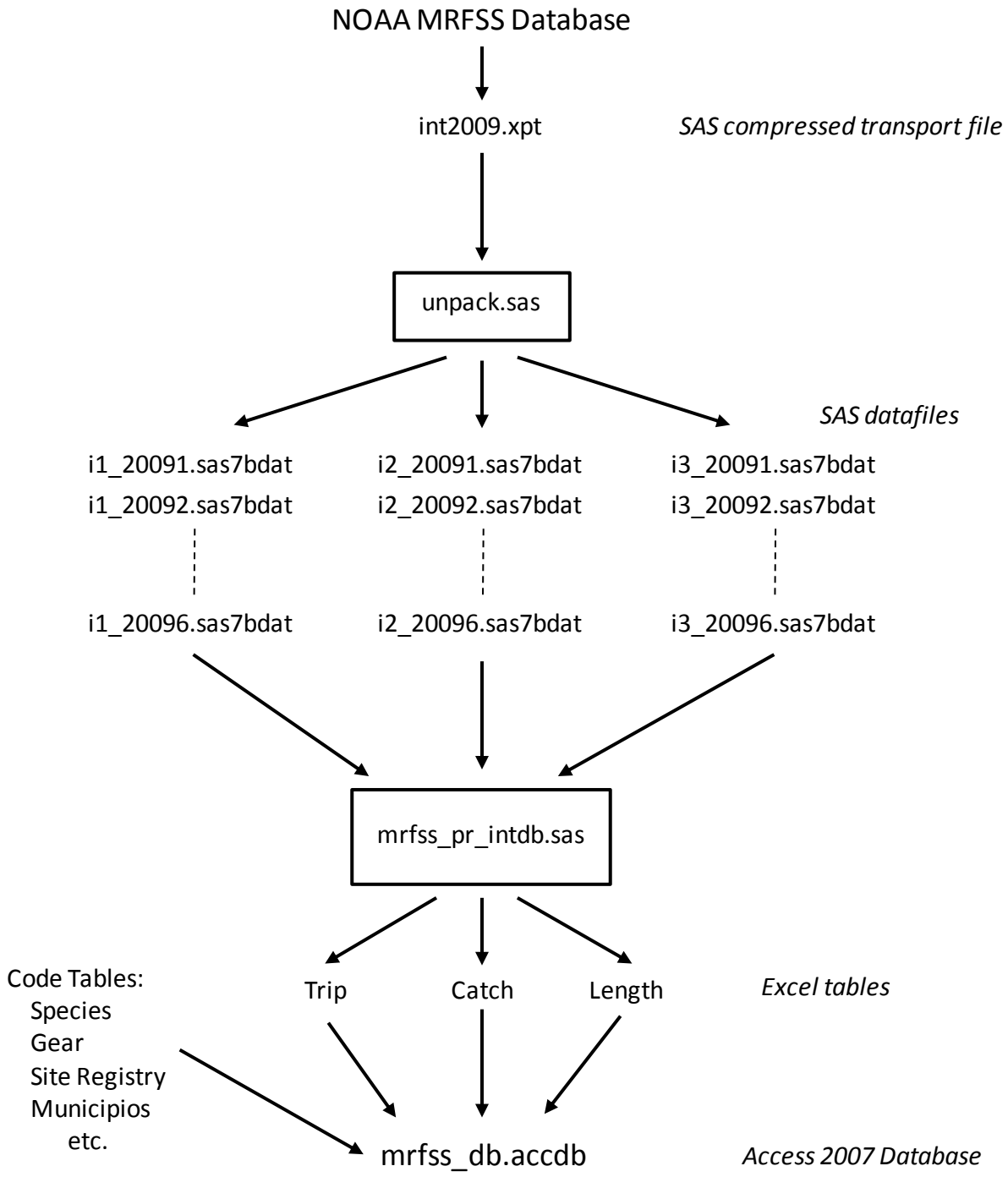

Table 1. Description of variables in the Trip information table of the MRFSS Access database for Puerto Rico .

Column_order	Variable	Type	Description
1	ID_CODE	Character	Intercept ID Code (identifies unique record)
2	YEAR	Integer	Year Data Collected
3	MONTH	Integer	Month Data Collected
4	DAY	Integer	Day Data Collected
5	TIME	Integer	TIME OF INTERCEPT
6	WAVE	Integer	WAVE OF DATA
7	ST	Integer	STATE OF INTERCEPT
8	MUNI_TRP	Integer	MUNICIPIO (ISLAND) OF TRIP
9	INTSITE	Integer	SITE CODE
10	SUB_REG	Integer	SUB REGION OF TRIP
11	MODE_F	Character	MODE OF FISHING (FISHERMAN)
12	MODE_FX	Character	MODE OF FISHING (FISHERMAN COLLAPSED)
13	AREA	Character	AREA OF FISHING
14	DISTKEYS	Character	DISTANCE FROM SHORE
15	AREA_X	Character	COLLAPSED AREA OF FISHING
16	GEAR	Integer	TYPE OF GEAR
17	HRSF	Real	HOURS FISHED
18	ADD_HRS	Real	ADDED HRS FISHED FOR INC TRIPS
19	HRS_DTD	Real	Hours on boat, other hours
20	PRIM1	Character	PRIMARY SPECIES SOUGHT
21	PRIM2	Character	SECONDARY SPECIES SOUGHT
22	FFDAYS12	Integer	DYS SALWAT.FINFIS.(LAST 12 MON.)
23	FFDAYS2	Integer	DYS SALWAT.FINFIS.(LAST 2 MON.)
24	ST_RES	Integer	State of Residence
25	MUNI_RES	Integer	MUNICIPIO (ISLAND) OF RESIDENCE
26	ZIP	Character	HOME ZIP CODE
27	PVT_RES	Integer	RESIDENCE TYPE
28	TELEFON	Integer	HAS HOME TELEPHONE
29	FIRST	Integer	FIRST PERSON INTERVIEWED IN PARTY
30	CNTRBTRS	Integer	NUMBER OF CONTRIBUTING FISHERMEN
31	SEP_FISH	Integer	SEPARATE CATCH BY FISHERMAN
32	PARTY	Integer	NUMBER IN FISHING PARTY
33	F_BY_P	Integer	FISH CAUGHT BY INDIVIDUAL INTERVIEWED

Table 2. Description of variables in the Catch information table of the MRFSS Access database for Puerto Rico .

Column_order	Variable	Type	Description
1	ID_CODE	Character	Intercept ID Code
2	SP_CODE	Character	Fish Species Code
3	CATCH_A	Integer	NUMBER OF FISH LANDED AND INSPECTED
4	DISPO_A	Character	DISPOSITION OF CATCH_A FISH
5	CATCH_B1	Integer	NUMBER OF FISH LANDED AND UNAVAILABLE FOR INSPECTION
6	DISPO_B1	Character	DISPOSITION OF CATCH_B1 FISH
7	CATCH_B2	Integer	NUMBER OF FISH CAPTURED AND RELEASED
8	DISPO_B2	Character	DISPOSITION OF CATCH_B2 FISH

Table 3. Description of variables in the Length information table of the MRFSS Access database for Puerto Rico .

Column_order	Variable	Type	Label
1	ID_CODE	Character	Intercept ID Code
2	SP_CODE	Character	Fish Species Code
3	LNGTH	Integer	FORK LENGTH OF FISH (MM)
4	WGT	Real	WEIGHT OF FISH (KG)

Key Data Needs for the Next Several Years:- Discussions of key data needs for the near-term future for building sustainable fisheries in Puerto Rico began with a review of fishing regulations pending final legal approval for correcting some of the overfishing problems identified in Technical Workshops #1 and #2. To date, sustainability analyses have been conducted on 34 reef-associated fish species; however, there are a number of reef species that are prominent in the landings of commercial and recreational fishers and thus have sufficient length composition data for sustainability analysis, but are lacking the requisite life history information on age & growth, lifespan, length at reproductive maturity, etc. These include species of the following taxa groups: deepwater snappers, parrotfishes, boxfishes, porgies, and goatfishes. Workshop participants unanimously agreed that conducting research on life history characteristics of these species should be a high priority in the next few years. Participants sketched out a blueprint for future research and funding to improve DNER's capacity for conducting life history studies.

Technical Workshop #3 concluded with a review and discussion of the principal sources of length composition and abundance data for Puerto Rico reef-fishes. Great strides have been made in the past few years in synthesizing and assimilating data from the Trip Interview Program (TIP) that samples the commercial fleet. Researchers from UM are currently working with their counterparts at NOAA's Southeast Fisheries Science Center to create a master database for Puerto Rico TIP information. This activity involves cross-checking and updating data records for the period 1988-2010 utilizing the original source digital files provided by DNER. Workshop participants were also briefed on a new fishery-independent diver visual survey of Puerto Rico reef-fishes to be conducted during the summer of 2014. Participants sketched out a blueprint for future research and funding to integrate fisheries databases for the commercial fleet (Trip Interview Program), the recreational fleet (MRFSS), and fishery-independent surveys.

Appendix
MRFSS Intercept Data Recording Form

2. NO. de MISION [ ] *Tache número "1" y escribe el número "2" si ésta es su segunda misión en el día*

3. ID. de ENTREVISTADOR [ ][ ][ ][ ]

4. AÑO/MES/DIA [2][0][0][8] [ ][ ] [ ][ ]

5. NO. de INTERCEPTO [ ][ ]

6. HORA de LA ENTREVISTA (Utilice el horario de 24 horas) [ ][ ][ ][ ] *Hora que completó la entrevista*

7. CLAVE DEL ESTADO [7][2] 8. CLAVE DEL MUNICIPIO [ ][ ][ ] 9. CLAVE DEL LUGAR [ ][ ][ ][ ]

10. ESTATUS DEL LA ENTREVISTA (Articulo clave = *)
- 1 [ ] Cuestionario Completo
- 2 [ ] Rehusó sin Anotación
- 5 [ ] Rehusó con Anotación

LEA EL ACTA DE PRIVACIDAD. **Este estudio se conduce de acuerdo al Acta Federal de Privacidad de 1974. No require que conteste preguntas que entienda invaden su privacidad.**

***11. ¿Diría que estuvo pescado desde ...**

SH
- 0 [ ] Muelle
- 1 [ ] Desembarcadero
- 2 [ ] Rompeloa, Espolón, Salidero
- 3 [ ] Puente, Paseo Tablado, Paseo (senda concreto)
- 4 [ ] Otra Estructura Artificial (Especifique) _____
- 5 [ ] Playa o Banco (Arena, Rocas, Acantilado)

(Solamente Para Playa o Banco- Tiempo adicional requerido en P-16)

PC
- 6 [ ] Bote con Tarifa
- 7 [ ] Bote Fletado

PR
- 8 [ ] Bote Privado
- 9 [ ] Bote Alquilado

***12. ¿Dónde dedicó (especifique modalidad) mayormente el esfuerzo hoy?** Elija solamente una respuesta.

- 1 [ ] Océano/gulfo/bahía abierta
- 2 [ ] Un Pasaje de Mar *(Otros más que los especificados)*
- 3 [ ] Río *(Otros más que los especificados)*
- 4 [ ] Bahía *(Otros más que los especificados)*
- 5 [ ] Otro (Especifique) _____
- N [ ] Estuario Boquerón
- O [ ] Estuario Guánica
- P [ ] Estuario Guayanilla
- Q [ ] Estuario Humacao
- R [ ] Estuario Jobos
- S [ ] Estuario San Juan
- T [ ] Estuario Tortuguero

Clave Preg. 13 como "8."

BOX A. ***Si la respuesta a la pregunta número 11 coincide con la modalidad "SH" (costera u orilla) Y la respuesta a la pregunta número 12 es "oceano/gulfo/bahía", el encasillado que debe marcarse es el "3" (10.3 millas o menos). (si la respuesta de la pregunta número 12 es una de los encasasillados "2" hasta "T", marcarse pregunta número 12 como "no aplica").***

***13. ¿El lugar está a ...**

- 3 [ ] diez millas o menos de la costa?
- 4 [ ] más de diez millas?
- 8 [ ] No aplica.

14. ¿Cùal fue el arte de pesca usado principalmente? Elija solamente una respuesta.

01	[ ]	Hilo y Anzuelo	07	[ ]	Trampa
02	[ ]	Red de Inmersión	08	[ ]	Arpón
03	[ ]	Atarraya	09	[ ]	A Mano
04	[ ]	Trasmayo	10	[ ]	Otro (Especifique)
05	[ ]	Chinchorro	11	[ ]	Yoyo
06	[ ]	De Arrastre	98	[ ]	Desconocido
			99	[ ]	Rehusó

15a. ¿En la proximidad de la media en punto (0.5), cúanto tiempo (horas) ha estado pescando (especifique modalidad) hoy? ¿En particular, cuántas horas (tiempo) ha estado con su arte de pesca en el agua?

[ ][ ] . [ ] *Clave como "99.9" si No Sabe o Rehusó*

15b. [PC y PR solo] ¿ En la proximidad de la media en punto (0.5), cuánto tiempo (horas) ha estado en el bote, fuera del desembarcadero, hoy?

[ ][ ] . [ ] Clave como "99.9" si No Sabe o Rehusó

[ ] No aplica – modalidad "SH"

16. (Preguntar si es la playa o banco) ¿Cúanto tiempo (horas) adicional permanecerá? ¿En particular, cuántas horas más mantendrá su arte de pesca en el agua?

[ ][ ] . [ ] Número de Horas (BB) Adicionales (Solamente si Preg. 11 = 5)

[ ] No esta pescando de la playa o banco

17. ¿Pescaba para alguna clase particular de pez? *¿Si es así, cúal clase de pez?*

[ ] No Tipos de Especies Particulares/Cualquiera

1er Objectivo _____ [ ][ ][ ][ ][ ][ ]

2ndo Objectivo _____ [ ][ ][ ][ ][ ][ ]

18. ¿Con excepción de hoy dentro de los pasados doce (12) meses, o sea des (mes del momento) de año pasado, cuántos dias pescó deportivamente en agua salada aquí en Puerto Rico?

[ ][ ][ ] No. de Días

- 998 [ ] No Sabe
- 999 [ ] Rehusó

19. ¿Con excepción de hoy, dentro de los pasados dos (2) meses, cuántos días?

[ ][ ] No. de Días

- 998 [ ] No Sabe
- 999 [ ] Rehusó

***20. ¿En qué municipio, pueblo o país (que no sea P.R.) reside?**

[ ][ ] Clave del Estado o País: Nombre _____

[ ][ ][ ] Clave del Municipio o Pueblo, Nombre _____

21. ¿Cúal es el código postal de su residencia?

[ ][ ][ ][ ][ ] Código postal

- 99997 [ ] País extrenjéro
- 99998 [ ] No sabe
- 99999 [ ] Rehusó

22. ¿Vive Usted en una residencia privada u otro tipo de vivienda como domitorio, militar, horgar de cuido especial (envejecientes) u hospedería?

- 1 [ ] Residencia Privada
- 2 [ ] Proyecto de Vivienda-Q. 23 debe ser "8"
- 8 [ ] No sabe
- 9 [ ] Rehusó

23. ¿Hay un telefono en su hogar que no sea celular?

- 1 [ ] Sí
- 2 [ ] No
- 8 [ ] No sabe/ No aplica
- 9 [ ] Rehusó

24. ¿Puede decirme su nombre y un nùmero de telefonó? Por si a caso me supervisora desea verificar (confirmar) que se realizan las entrevistas?

NOMBRE DE PESCA (Si el nombre y/o el número de teléfono no se dan, Preg. 10 = estatus 2)

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

☐ No dío nombre o nùmero de teléfono

D. o N. NO. TEL. (☐☐☐) ☐☐☐ - ☐☐☐☐

☐ Angler aged 16 years or younger

***25 CAPTURA NO DISPONIBLE. ¿Pescó algo que ya no está aquí para verlo? Por ejemplo cualquiera pescado que haya devuelto al mar o usado como carnada. SI LA REPUESTA ES Sí, COMPLETE EL REGISTRO TIPO 2 PARA ESTE PESCADOR INDIVIDUAL, NO CAPTURA GRUPAL.**
NO INCLUYA NINGÚN PEZ QUE FUERA CAPTURADO POR OTRO PESCADOR. **NOTA: PESCADOS-REBANADOS SE CONSIDERAN NO DISPONIBLE.**

CLAVES PARA LA DISPOSICION DE LA CAPTURA – PREGUNTA 25

1 Devuelto vivo/ legal
3 Consumido/ por consumir
4 Usado como carnada/ por usarse como tal
5 Vendido/ por venderse
6 Devuelto muerto/ piensa hacerlo
7 Otra disposición

BOX B. ¿Captura Tipo "2" es del grupo?
☐ Sí ☐ No

(Si la respuesta es sí – favor, recordarse que la captura tipo "2" no es del grupo !)

TIPO 2 ARCHIVO: ***(CAPTURA INDIVIDUAL - NO DISPONIBLE INTACTA)***

	CLAVE DE LA ESPECIE	NO. DE PECES	DISP.
1. _____	☐☐☐☐☐☐	☐☐☐	☐
2. _____	☐☐☐☐☐☐	☐☐☐	☐
3. _____	☐☐☐☐☐☐	☐☐☐	☐
4. _____	☐☐☐☐☐☐	☐☐☐	☐
5. _____	☐☐☐☐☐☐	☐☐☐	☐
6. _____	☐☐☐☐☐☐	☐☐☐	☐
7. _____	☐☐☐☐☐☐	☐☐☐	☐

***26. ¿Capturó (pescó) algo que me permita observar (examinar)?**

1 ☐ **Sí**

2 ☐ **No** – *Marcarse preguntas 27, 28, y 29 como "No Aplica"*

3 ☐ **Sí – pero los peces estan registrados en el formulario de otro pescador -** indique el número de la entrevista donde aparecen registrados*

* ☐☐ – *Clave preguntas 27, 28, y 29 como "No Aplica"*

***27. ¿Los capturó usted solo o alguien lo ayudó?**

1 ☐ **Todos capturados por el pescador** – *Clave preguntas 28 y 29 como "No Aplica"*

2 ☐ **Otros Colaboradores** 8 ☐ **No Aplica**

***28. ¿Puede separar los peces que capturó? ¿Puede separar su pesca del resto?**

1 ☐ **Sí** – *Clave 29 como "No Aplica"*

2 ☐ **No** 8 ☐ **No Aplica**

***29. ¿Cuántos pescadores, incluyéndo a usted, tienen la pesca aquí? Por favor, no incluya a los que no capturaron peces. Solo cuente los pescadores que tengan la captura en el lugar.**

☐☐ **No. de Colaboradores** 88 ☐ **No Aplica**

BOX C. ***Si preg. 11 coincide con la modalidad (SH), clave preg. 30 como "88, " y Clave Box D como "8."***

***30. ¿Cuántas personas pescaron hoy en su bote?**

☐☐☐ **No. de Personas** 888 ☐ **Modalidad de orilla**

***Box D. Si la respuesta a la pregunta 30 es 1, marcarse "No Aplica." De otro modo, ¿Es el primer pescador del bote que he entrevistado?**

1 ☐ **Sí** 8 ☐ **No Aplica**

2 ☐ **No** – *Registre el nùmero de la entrevista al primer pescador del grupo de pesca (partida de pesca). **

☐☐

***31. CAPTURA DISPONIBLE – PREGUNTARLE (LA): ¿Puedo ver su pesca? ¿Qué piensa hacer con la MAYORIA del los (especies)?**

CLAVES DE DISPOSCION PARA PREGUNTA 31

3 Consumido/por consumir
4 Usado como carnada/será usado concarnada
5 Venderlo/por venderse
6 Devuelto muerto/por devolverse
7 Otro intención
8 No sabe/No pregunté
9 Rehusó

NOTAS/COMMENTAS:

TIPO 3 ARCHIVO: ***(CAPTURA INDIVIDUAL - DISPONIBLE INTACTA)***

	CLAVE DE LA ESPECIE	NO. DE PECES	MEDIDA LARGO (mm)	PESO (kg)	DISP.
1. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
2. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
3. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
4. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
5. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
6. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
7. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
8. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
9. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
10. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
11. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
12. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
13. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
14. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐
15. _____	☐☐☐☐☐☐	☐☐☐	☐☐☐☐	☐☐☐.☐☐	☐